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The use of remote sensing for soil survey in Iowa

Earl Dean Lockridge
Iowa State University

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by

Earl Dean Lockridge

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INTRODUCTION[1]

Aerial photographs have been used since the late 1920's as a base on which to plot data about soils and to draw boundaries between kinds of soils (Colwell, 1966). At present soil scientists in every state use them as a base on which to plot soil boundaries.

It requires a great deal of effort to make an accurate soil map. The soil scientist must cover many thousands of acres each year, examining the types of soil on the landscape. Each time the soil scientist examines a soil he must probe to depths of 24 to 48 inches with a specially made soil probe that takes a core of soil. Because of this, it requires a tremendous amount of time to cover the thousands of acres mapped each year. Any device or technique which will provide clues regarding the soil type that might occur on the landscape could save time and also allow the soil boundaries to be placed more accurately.

Black and white panchromatic aerial photographs have been used to supply many clues regarding possible soil patterns. Soil patterns are repeated over an area and by studying these patterns in the field and relating them to tonal patterns on the aerial photographs, the soil scientist can utilize these photographs to more accurately plot soil boundaries.

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[1]A part of the imagery was furnished for this project under NAS5-21839, Goddard Space Flight Center, Greenbelt, MD.

These aerial photographs do, however, have limitations. First of all, they do not allow the soil scientist to "see" a soil. Photographs only reflect degrees of tonal variation and this variation is only what occurs on the surface of the landscape. Secondly, soils have a third dimension which does not show on the aerial photographs because only the surface characteristics are recorded on the photograph. This is why the soil scientist must still make detailed examinations of the soil in the field when making a soil map.

It is not the purpose of this research to discover a method which will eliminate the need for the soil scientist to examine the soil in the field, but rather to determine if there are other types of remotely sensed imagery in addition to or in lieu of the presently used black and white imagery which will enable the soil scientist to even more accurately plot soil boundaries in a shorter amount of time.

Soil maps are being used by more and more people and organizations each year. With the increased use comes a demand for increased accuracy in combination with increased production.

The types of imagery to be tested are color infrared, thermal infrared and multispectral. The use of an I^2s color additive viewer[1] will also be examined as a possible method

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[1]Taranik, J. V., Iowa State University. Classroom discussion. 1973.

of mechanically delineating soil boundaries based on the tonal patterns of the color infrared imagery.

LITERATURE REVIEW

Early History

Remote sensing, as defined in its broadest sense by Colwell (1966) as "reconnaisance at a distance", has been a tool used by man since the beginning of time. This activity began when man first tried to "sense" the presence of an animal by either sight, smell, or sound. It does not then, in its broadest sense, represent a new area of study. However, within a more restrictive definition by Rabchevsky (1970) as the activity involved in detecting electromagnetic radiant energy from a distance, it is a relatively new field.

The earliest of the remote sensors is photography. It began in 1839 when Louis J. M. Daguerre of Paris invented a positive-image process for making portraits (Avery, 1968).

A few years later another investigator, William H. Fox-Talbot, developed the negative-positive process of film processing that is still in use today (in Avery, 1968).

Development of better cameras and films continued and with the advent of better sensors, photography took to the air. Aerial photographs (an early form of remote sensing) were taken even before the Wright brothers' first historic flight in 1903. Laussedat, in the early 1850's, used kites and captive balloons to take aerial photographs (Avery, 1968).

Baldwin et al. (1947) reports that as early as 1926, two soil scientists, who had been pilots in the war (T. M. Bushnell then in charge of Soil Survey at Purdue University and Mark Baldwin of the Division of Soil Survey in the United States Department of Agriculture), enlisted the help of the Army Air Force to fly a photographic mission for soil survey purposes over Jennings County, Indiana. This proved successful and by the early 1930's most of the arable land in the United States had been flown and photographed using black and white "panchromatic" film which is sensitive to all colors (Colwell, 1966). This imagery involved visible electromagnetic energy. At the close of World War II photographic techniques emerged which enabled photographic film to record electromagnetic energy not visible to the eye (Taranik, 1972). Taranik (1972) also reports that in the early 1950's the military perfected scanners and sensors capable of recording wavelengths not detectable by conventional photographic means. With the development of these many sensor systems, scientists have been trying to develop new uses for them.

Technical Aspects of Remote Sensing

In order to better understand how these systems can be used, a discussion of the technical aspects of remote sensing is presented in the following paragraphs.

As stated earlier, one of the earliest sensors used was the human eye. A source of electromagnetic energy (the sun) is reflected from our surroundings and is picked up by sensors (our eyes). These sensors are able to distinguish radiation in various wavelengths, and, therefore, we are able to see colors.

To better explain this, look at the diagram of the visible portion of the electromagnetic spectrum (Figure 1). The human eye is able to detect radiation in the wavelength region from .7 microns to .4 microns. This is the region from which all colors are distinguished by our eyes.

A camera, which is another sensor, works in the same manner as our eyes. Hoyer (1972) describes the process in this manner: Solar energy is emitted from the sun. This energy is reflected from earth materials and passes through the camera lens (the eye) to expose a film within the camera.

Black and white film is composed of two layers: An acetate or polyester layer that provides the base for the film and an emulsion layer which is a gelatinous matrix with billions of photosensitive crystals throughout. The crystals are generally silver bromide. Also, there is added to the emulsion a binding agent which makes the emulsion adhere to the base. Basically, all black and white panchromatic film involves the same materials.

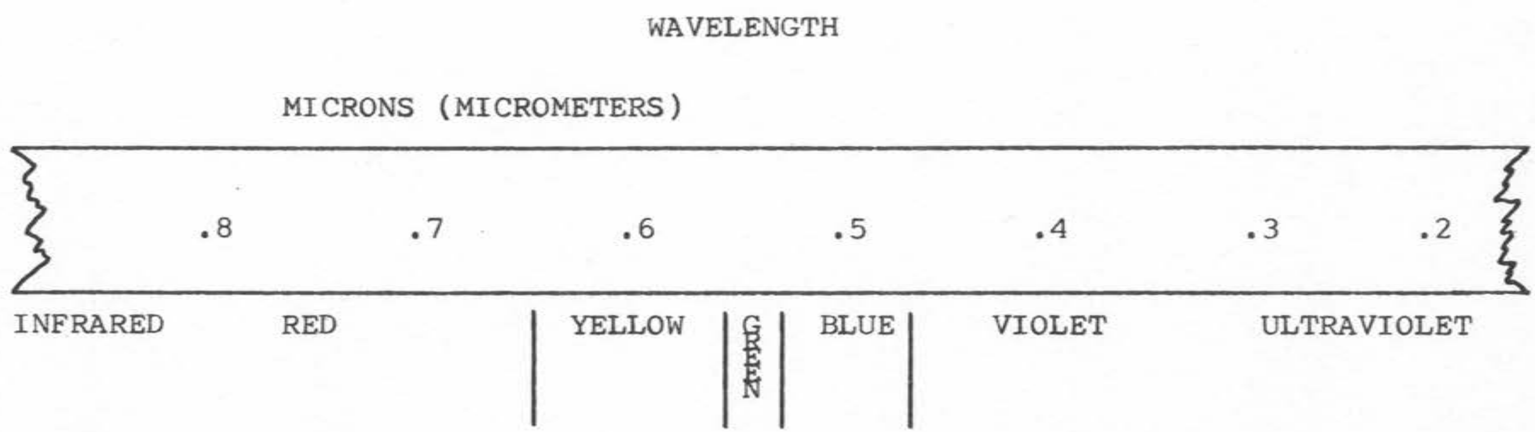


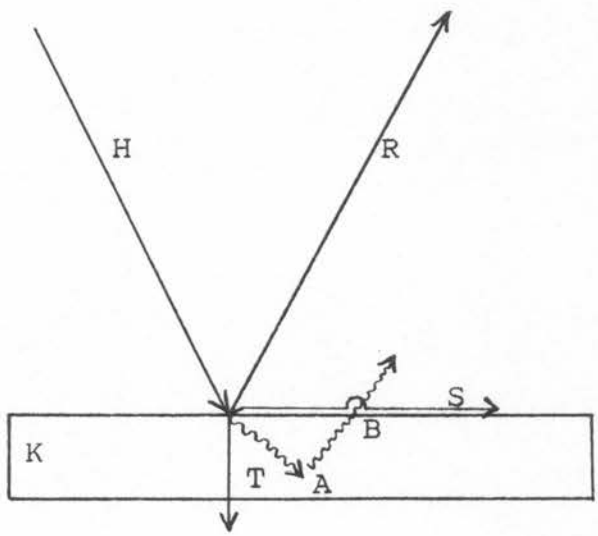
Figure 1. Visible portion of the electromagnetic spectrum

Electromagnetic energy has the sun as its natural source. As explained in Figure 2 from Taranik (1972), there is a certain amount of incident energy (H) which reaches the target (K). There are four possible processes which may occur immediately: (1) The energy may be reflected from the target as at (R); (2) The energy may be absorbed into the target as at (A); (3) The energy may be transmitted through the target as at (T); (4) The energy may be scattered as at (S) and lost ultimately to absorption or further scattering. At some point in time the energy that has been absorbed may be emitted in the form of heat as at (B).

Reflected energy is that energy recorded on photographic film. Emitted energy is recorded by another sensor, namely a thermal scanner. This sensor is able to scan the earth's surface from a high altitude, and, at low altitudes, record differences in temperature at the earth's surface as small as 0.5°C (Parker, 1972). These differences are reproduced in black and white as line scans and look much like a photographic image.

Absorbed energy from the sun is only one source of heat emitted at the surface of the earth. Others can be seen in Table 1.

Another nonphotographic sensor is radar. However, radar imagery was not required in this study and will not be



H — Incident Energy

R — Reflected Energy

T — Transmitted Energy

A — Absorbed Energy

B — Emitted Energy

K — Target

Figure 2. Characteristics of incident energy

Table 1. Sources of ground heating and cooling

Natural	Man Made
Heating--	Heating--
a. sun (radiant heating)	(thermal pollution) - industries, nuclear reactors, etc.
b. atmosphere (radiant heating and wind)	
c. geothermal	
1. from earth's center	
2. heat producing natural chemical reactions	
Cooling--	
a. radiant cooling	
b. atmosphere (wind)	
c. evaporation of H_2O	
d. transpiration of H_2O from plants	

discussed.

The eye can detect several colors as they are transmitted from an object. Taranik (1972) explains that colors are a result of our physiological reactions to wavelength distributions of radiant energy. "The color sensations that we can see are brightness (the amount of radiant energy), saturation (the degree of color purity), and hue (the spectral distribution of radiant energy)" (p. 60) (Figure 3).

White is produced by combining equal parts of the three

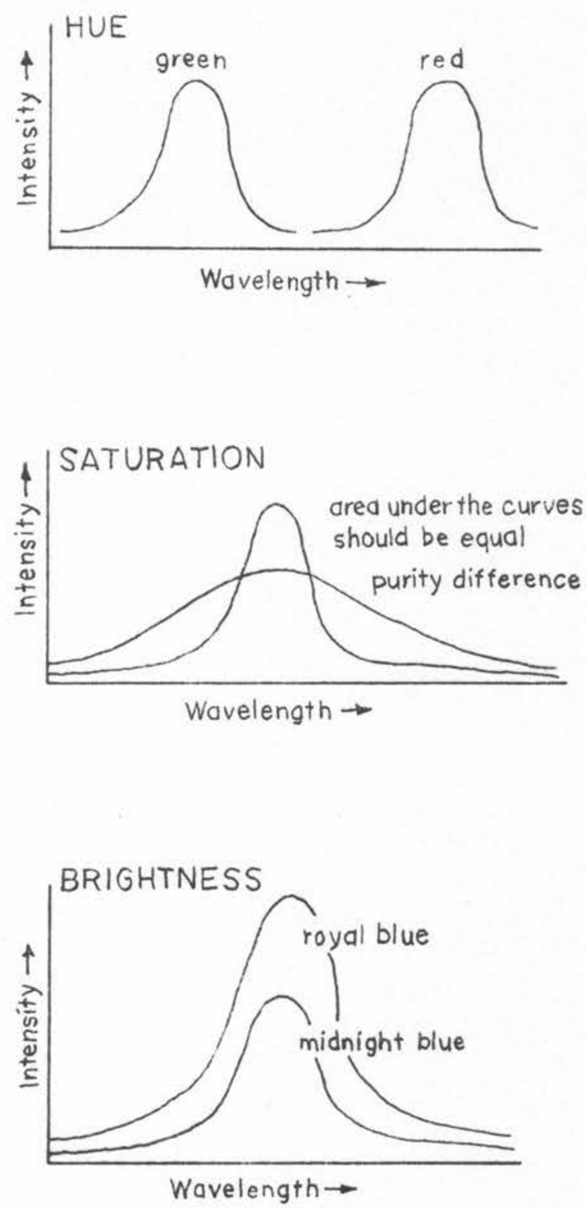


Figure 3. Visible color sensations

primary colors red, green and blue. When viewing a color photograph, white light is present initially, then proportional amounts of blue, green and red are subtracted to form the desired colors.

Color films are a direct result of the action of three primary subtractive dyes: (1) Yellow--absorbs blue; (2) Magenta--absorbs green; (3) Cyan--absorbs red. The appropriate quantity of each dye is then produced when the film is exposed and processed (Taranik, 1972).

Taranik (1972) lists three types of color films. The first type is color reversal film. This type of film gives a positive image having the same color as the original scene. After processing, the dyes are present in amounts inversely proportional to the log of the exposure reaching a given area and layer of film. The formula for this is: Dye amount = $\frac{1}{\log_{10} E}$ where E = exposure.

The second type is color negative film. Upon exposure each color is recorded on the emulsion layer which is sensitive to that wavelength. The cyan layer is sensitive to red, the magenta layer is sensitive to green and the yellow layer is sensitive to blue. The other colors are recorded proportionately on two or more layers. During the developing step the dyes are formed by the action of couplers reacting with the oxidation products from the developer and silver halide. The dyes are formed in proportion to the amount of silver developed (Figure 4).

The third type of color film is the false color infrared film. It is a three layer film with two of the layers sensitive to visible wavelengths and one layer sensitive to invisible electromagnetic radiation. The reason it is called "false color" is the fact that the invisible reflected infrared is assigned a red dye forming layer while the normally green and red visible band passes are assigned blue and green dye forming layers respectively. The portion of the electromagnetic spectrum involved in this photographic process is the near infrared band from .7 microns to 2 microns (Figure 5). A yellow filter such as the Wratten 12 or 15 is used to absorb blue wavelengths of radiation.

Another type of photography is multiband photography. The goal of multiband photography is to identify those wavelength bands that best show tonal differences between materials. The instrument used is either a multiple camera cluster or one camera with multiple lenses. Four different images are recorded on the same object simultaneously. Each lens is selective for a particular wavelength band. Thus, different wavelengths can be examined and the one which shows the greatest tonal difference for that object is identified for later use and comparison.

The reason this sensor system is needed results from the fact that different objects have peak reflectance in

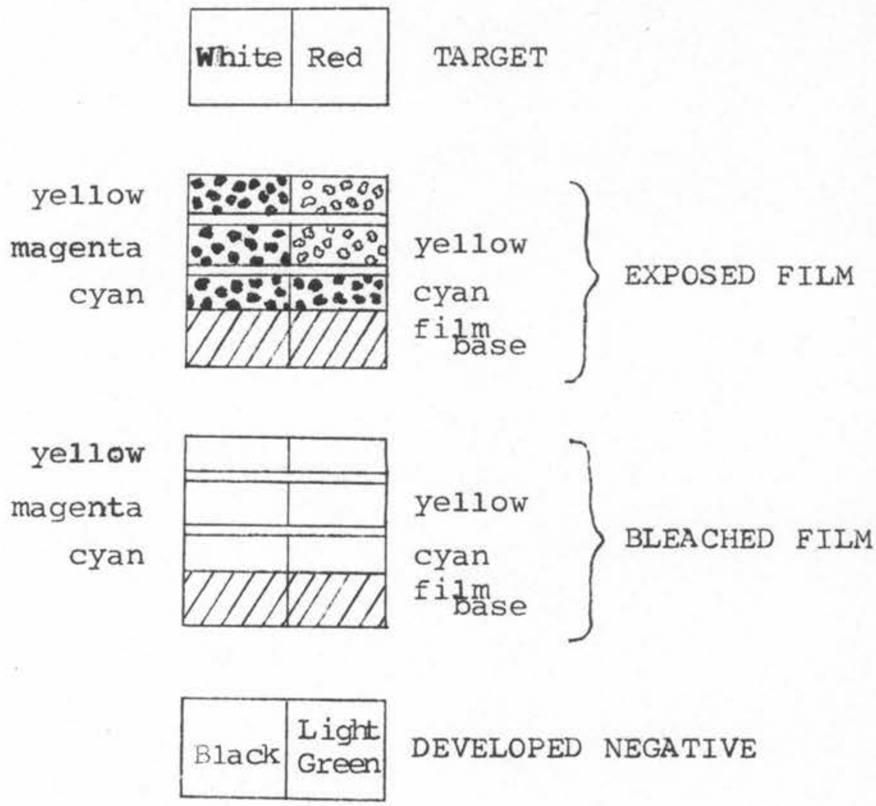


Figure 4. Process of development of color negative film

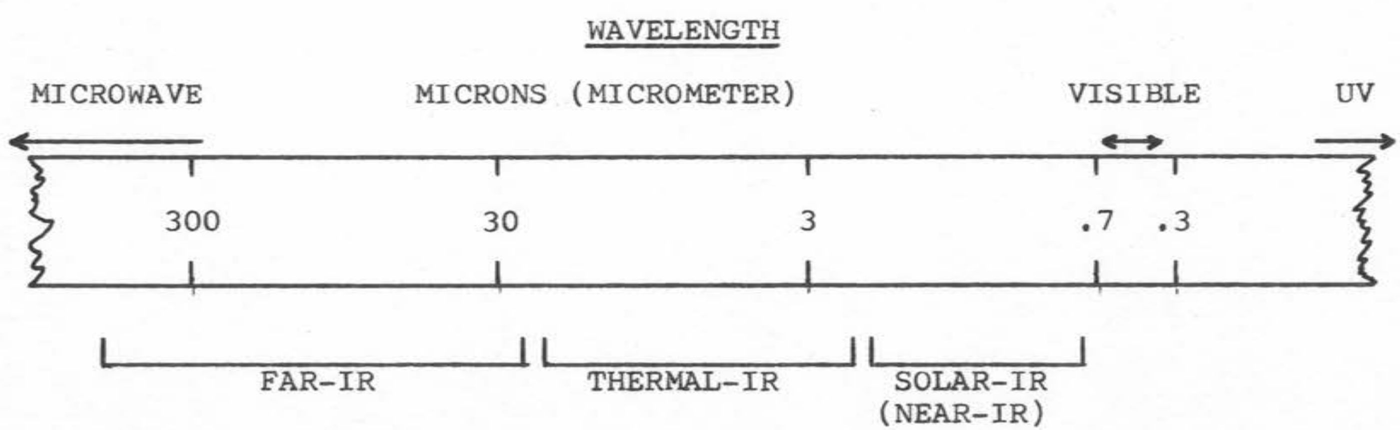


Figure 5. Infrared portion of electromagnetic spectrum

different bands as shown in Figure 6 (Taranik, 1972).

Previous Studies

Remote sensing as a science is a relatively young discipline. Early attempts in the early 1850's utilized kites and captive balloons (Avery, 1968).

In the late 1920's and early 1930's remote sensing became popular as a means of acquiring imagery for the purpose of inventorying soils and delineating soil boundaries. Before that time, the mapping of soils was done with the use of a planetable. The use of aerial photographs made possible more accurate plotting of soil boundaries and speeded up the process of mapping soils (Soil Survey Staff, 1966).

There has been much research concerning the possibility of using various forms of remote sensing imagery to identify, evaluate and delineate soils.

Most of the research done in the early studies utilized panchromatic film. This is a black and white film that is sensitive to all visible wavelengths.

After Baldwin's study (Baldwin et al., 1947), there were several attempts to determine the possible uses of the imagery acquired and the limitations concerning interpretations of soils. Rourke and Austin (1951) reported that soil boundaries could be plotted accurately and quickly, but sound classification and mapping could only be done by

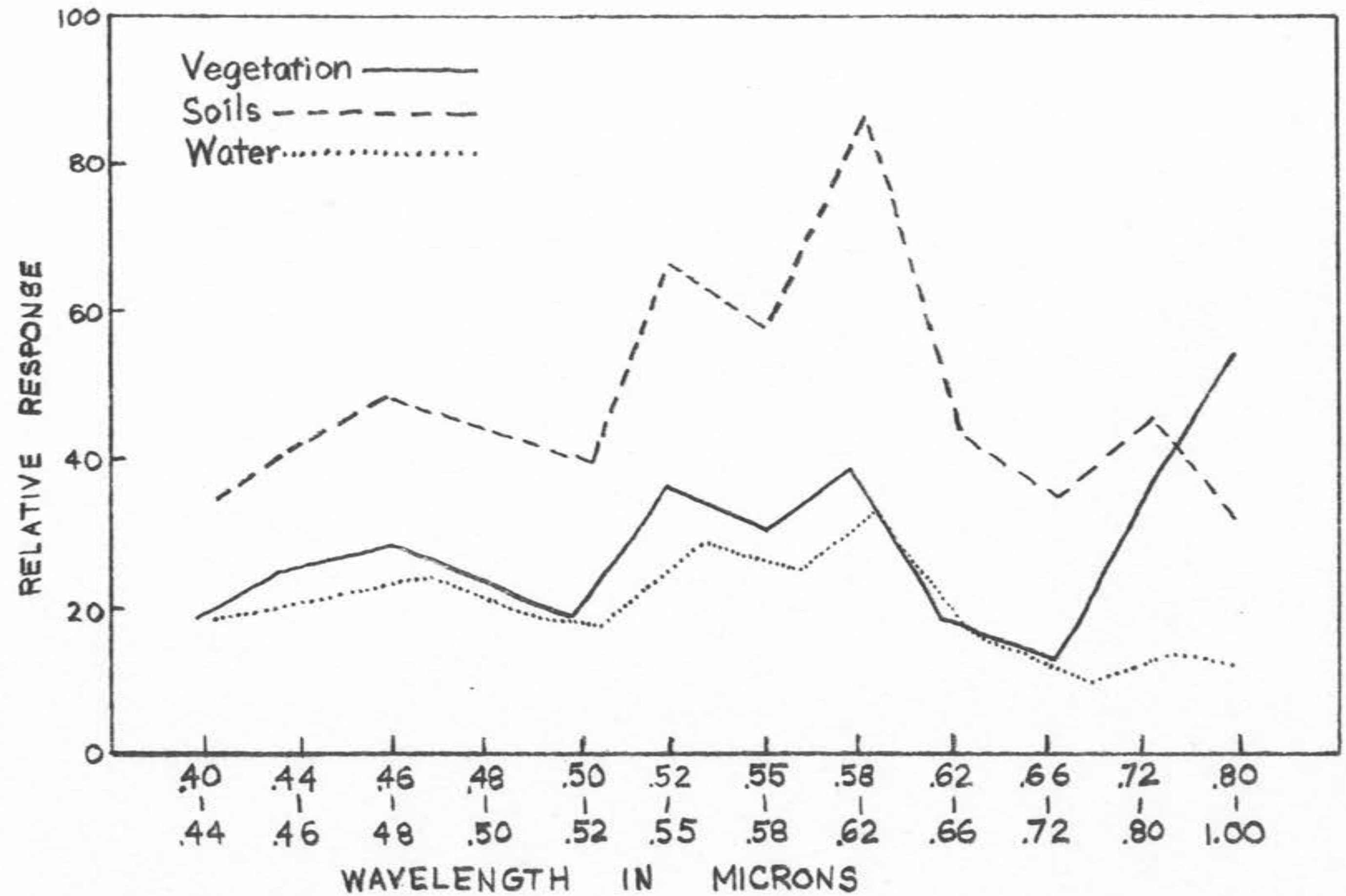


Figure 6. Reflectance chart for vegetation, soils and water

detailed field studies of the soils themselves. They found that aerial photographs do show soil patterns, but not soil profiles, and, to the competent soil scientist who has studied the soils of each pattern on the ground, these photographs do suggest the kind of profiles present.

What goes into the interpretation of an aerial photograph? In the Manual of Photogrammetry (American Society of Photogrammetry, 1952) several basic considerations are listed in photo interpretation. These are listed below:

1. Shape--general form, configuration or outline of a particular object.

2. Size--size often gives clues to the identity of an object.

3. Pattern--spatial arrangement of objects.

4. Shadow--the shape of the shadow often gives a clue to the identity of the object.

5. Tone--the brilliance with which light is reflected by an object. This is one of the best clues and often the only clue to the identity of an object.

6. Texture--the frequency of tone change within the image.

7. Site--location of the object in relation to the other features (pp. 536-540).

Of these seven considerations, tone is considered by many to be the most important for soil mapping and interpretation. The Manual of Photographic Interpretation (American Society of Photogrammetry, 1960) reports that tone is probably the primary factor for image interpretation in remote sensing in agriculture and defines tone as "each distinguishable shade variation from black to white" (p. 343).

Hoffer et al. (1966) gives a more technical definition of tone as "the relative intensity of photons impinging upon a silver halide plate, in the visible and near-visible portions of the spectrum, as reflected from the objects viewed by the camera".

Lueder (1959) thought that the tone changes observable on photographs might indicate changes in texture or drainage conditions.

Winkler (1962) conducted a study to determine the relationship of airphoto tone control on moisture content in soils developed from glacial till. In this study pictures were taken of soil samples with known moisture contents using several types of film. Densities of the films were then measured. Next a ground study was conducted with moisture contents taken within 30 minutes of the flight. The results of this study indicated that soil moisture could not be determined by aerial photography.

Winkler (1962) concluded that the soil dries at a nonuniform rate. Drying starts with a thin layer on the surface. Organic matter content darkens a dry soil and distorts the tone of a wet soil.

The _Manual of Photographic Interpretation_ (American Society of Photogrammetry, 1960) lists additional factors which may be responsible for tonal differences. These factors include the angle of sun, light sensitivity of film, light transmission by the filter, and techniques of processing and printing the imagery. Kristoff and Zackery (1971) add to this list differences in surface roughness. Thus there are many variables involved in tones on aerial photographs but these tones form patterns which are used as clues to enable the soil scientist, with the aid of field investigations, to plot soil boundaries when making a soil map.

The second most important factor in interpreting remotely sensed imagery is tonal pattern. When using tonal patterns to interpret soils on any remotely sensed imagery, there are three important principles involved (American Society of Photogrammetry, 1960). First of all, similar soils appear in similar patterns. Secondly, dissimilar soils appear in dissimilar patterns. And thirdly, once photographic image characteristics have been correlated with soil properties observed in the field and laboratory, the sequence of events which formed a particular soil can be reconstructed by means of aerial photographic interpretation, and many important properties of similar soils can be inferred.

A third consideration that is quite important in remote sensing imagery interpretation is site or location of the object with respect to other objects. Position on the landscape and the type of parent material in the area has a great influence on the soils that could be present at any given location. Also the vegetation in the area could be a deciding factor.

Previous sections have emphasized black and white imagery. For quite some time only black and white imagery was available for use by soil scientists. When other types of imagery did become available, the cost was very high. Several studies were conducted on the use of color photography for soil interpretation and mapping. Most of the same considerations that were needed in interpreting black and white imagery apply to color imagery.

Evans (1948) explained that, at best, the human eye can only distinguish approximately 200 gradations on the neutral or gray scale, whereas it is capable of differentiating more than 200,000 different hues and chromas.

A study comparing color imagery of bare soils and black and white imagery of the same bare soils in terms of quanta of information which can be extracted by interpretation was conducted by Parry et al. (1969).

Soil colors were determined in the field and recorded by hue, value and chroma. The color imagery presents more chances for differentiation between soil types than did the black and white imagery. Soil colors in the field and on the film did not correspond exactly. The researchers concluded that "It is apparent that considerable advantages exist in using color film in attempting to identify and plot soil boundaries, in differentiating soil types within a series, and in distinguishing changes within a single soil type resulting from differences in moisture and organic matter content" (Parry et al., 1969, p. 56).

After comparative tests of black and white and color imagery, Anson (1968) pointed out that the problem with the use of the latter arises in the methods used to acquire the color information.

Cihlar and Protz (1972) conducted studies on a dissected lacustrine plain using black and white and color imagery. The film obtained was evaluated using an Automatic Scanning Microdensitometer Model 1010 and recording density levels eventually to a map form. They concluded that color photography did produce some specific information that black and white imagery did not. Areas of similar surface color could be interpreted and mapped.

The soil properties of moisture and texture were studied by Piech and Walker (1974). The purpose of this study was to determine what soil property caused the tonal difference on color imagery. (Both increasing soil moisture and decreasing particle size will darken tone.) Through a process of complicated equations and a sophisticated experimental photo-interpretation console, these differences could be calculated and the properties inferred.

Research conducted in England and Wales by Carroll and Evans (1971) indicated that color photography was not justifiable because the cost did not compensate for the little increase in ability to interpret aerial photographs. The reason for the conclusion reached by these scientists was the large amount of vegetative cover and the weather conditions which made it very difficult to obtain good imagery.

Another form of color imagery is color infrared or "false color". The characteristics of this type of imagery were discussed previously.

Gerbermann et al. (1971) compared the use of color and color infrared film for soil identification. They used air dry samples and took pictures of them in containers using both types of film. The optical density of each sample was measured. Twelve soils were studied. They can be divided into two groups for soil identification. They concluded that color imagery was best for identifying soils with high chromas and color infrared imagery was best for identifying soils with low chromas.

Multispectral imagery, as discussed earlier, is used primarily to define spectrally separable classes and determine which wavelength is best suited for a particular study.

Tanguay et al. (1969) analyzed multispectral imagery along a 70 mile flight line in Indiana. Six bands were studied. They were as follows:

1. thermal infrared band (8-14 microns)
2. reflective infrared band (0.8-1.0 microns)
3. red band (0.62-0.66 microns)
4. green band (0.52-0.55 microns)
5. blue band (0.40-0.44 microns)
6. ultraviolet band (0.32-0.38 microns)

The bands that showed the greatest soil contrasts were bands 3 and 4. Band 2 proved useful to detect and distinguish vegetatively covered ground from bare soil areas. Band 1 proved useful to detect bodies that were relatively hot and emitting strong radiation or relatively cool and emitting much less radiation. Most soil areas were of the same intermediate gray tone except for a few special features. This band allowed detection of some features that could not be detected on other imagery.

With the advent of space flight there is some extremely small scale imagery available. It was acquired by the Earth Resources Technology Satellite and is called ERTS-1 imagery. It is at a scale of 1 inch equals 500 miles. More recently Skylab imagery was acquired by a manned space laboratory. ERTS-1 imagery has been investigated because of its potential for soil identification purposes.

In a study in Texas by Baumgardner et al. (1973) it was shown that large associations of similar soils could be delineated using ERTS-1 imagery.

In a similar study, Parks and Bodenheimer (1973) reported similar results. There are two ways of accomplishing these delineations of soil associations. One is by looking at the bare soils and the other is by the contrast in vegetative cover and land use patterns among different association areas.

Much of the information is now being tested and analyzed using computers and digital analysis. Digital analysis is capable of producing computer-generated maps.

Zackery et al. (1970) used three study areas which were field mapped at medium intensity using conventional soil survey procedures. Base photos were color on one area and black and white on the other two areas.

Area multispectral scanner data was collected and analyzed on the computer. The resulting classification was based only on the spectral data. It was found that definite relationships existed between the multispectral imagery and soil types.

Cipra et al. (1972) did similar research on a 12 mile flight line in White County, Indiana. The purpose of this study was to determine the extent to which spectral properties of soil surfaces can be associated with morphological and topographic differences of interest to soil surveyors engaged in operational soil mapping.

Three groupings of soil mapping units were differentiated spectrally. These three groups corresponded to some extent to management groups. A one to one correspondence was found to be very unlikely for the glacial soils of western Indiana.

An attempt was made in Imperial Valley, California (by Anuta et al., 1971), to determine the feasibility of using a computer to digitize multispectral scanner data and, by training with known soil types, to print a soil map of the area.

It was found that on bare soil only broad scale maps could be produced with good results.

Another type of mechanical analysis is the density slicing technique using a Digicol density slicer. This is a technique in which line scans are run on the imagery and various densities are recorded. A print-out of a map showing the various densities in different colors is possible by use of an I^2S color additive viewer. An acreage summary of all densities is also possible.

It was concluded by Frazee et al. (1971) that this method is limited mainly by the quality of images available for interpretation.

Pomerening and Cline (1953) clearly demonstrated that methods which rely entirely on aerial photographic interpretation for final identification of mapping units produce less detailed and less accurate soil maps than those which rely upon field identification and delineation but use airphoto interpretation to guide the placement of boundaries. There are no methods presently available that completely eliminate the need for field checking when interpreting any kind of imagery.

Lueder (1959) outlined the process by which the soil scientist should go about mapping soils using aerial photographs.

There is first the initial phase. In this phase all the available information and maps relating to the areas of interest and adjacent areas are collected and studied. Also a few random traverses are made and photos are studied carefully. The second phase is the delineation of soil classes on photographs using photo interpretation. The third and final phase is the validation of these interpretations by further sampling and field checking.

Even with this process there are still factors that limit the use of aerial photographs for soil and terrain analysis. Frost (1953) listed and explained a few of the more important ones.

The first limitation is photographic scale. As in the case of ERTS-1 and Skylab imagery, the scale is too small for soil series analysis and at best only soil associations can be interpreted from this imagery. Secondly, too small or too large a coverage will limit the use of the photographs.

Human ability or the background experience and training of the interpreter will limit use. The fourth limitation is the natural features of the terrain pattern such as tone, erosion, and vegetation.

The last limitation is the method by which the imagery is obtained. As a result of recent discoveries in the field of photography and remote sensing there may be types of imagery which will better enable the soil scientist to map soils more accurately and with greater speed.

Simakova (1964) maintains that aerial photographs give the viewer a better knowledge of the area and thus enables him to plan his work more efficiently. There is a considerable reduction in the number of cores (cuts) required to map a section of land and, therefore, in the volume of field work.

Baldwin et al. (1947) states that "The primary determining factor as to the usefulness of aerial photography is the increased accuracy and amount of soil information obtained and not always the time saved in the mapping process" (p. 535).

In Iowa the soil survey program entails very detailed soil mapping. With the increase in the amount of interpretative work being done for land use planning around the larger towns and cities, there is a need for these detailed soil maps.

The newer types of imagery, such as thermal infrared, color infrared and color need to be extensively tested in Iowa for possible incorporation into the soil survey program as a tool to aid in the mapping process.

STUDY AREA LOCATIONS AND DESCRIPTIONS

This study was conducted in three areas of Iowa representing three different soil association areas. These associations and their locations are the Clarion-Nicollet-Webster in Boone county; the Kenyon-Floyd-Clyde in Buchanan county; and the Galva-Primgar-Sac in Lyon county (Figure 7).

Boone County Area

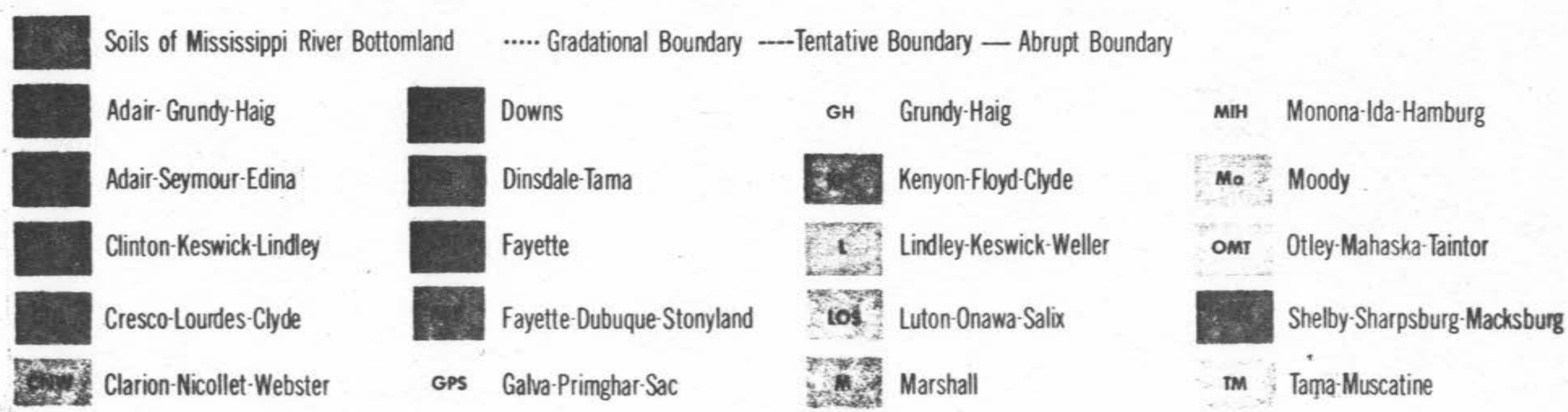
The Boone county study sites are located in a two-mile wide flight line along the south edge of highway 30. It stretches from the Des Moines river east to the Boone-Story county line. The crosshatched area in Appendix B shows the area.

The landscape in this area is characteristic of the greater part of the Clarion-Nicollet-Webster soil association. The topography is nearly level to moderately sloping although in places steeper slopes are present. The most outstanding features are the low lying plains which are covered with saucer-like depressions and low knobs and ridges rising slightly above this plain.

The four primary soils on the landscape in the association are the Clarion, Nicollet, Webster and Canisteo soils with a few other minor soils (Figure 8).

The Clarion soils occur on the higher knolls of the area

Figure 7. Soil association map of Iowa




OSCEOLA
DICKINSON
EMMET
KOSSUTH
WINNEBAGO
WORTH
MITCHELL
O'BRIEN
CLAY
PALO ALTO
HANCOCK
CERRO GORDO
FLOYD
CHEROKEE
BUENA VISTA
POCAHONTAS
HUMBOLDT
WRIGHT
FRANKLIN
BUTLER
BLACK HAWK
PLYMOUTH
WOODBURY
SAC
CALHOUN
WEBSTER
HAMILTON
HARDIN
SIOUX
GPS
CNW
GREENE
STORY
MARSHALL
TAMA
POWESHIEK
DALLAS
POLK
JASPER
TM
MUSCATINE
SCOTT
KEOKUK
WASHINGTON
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DES MOINES
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AUH
APPROXIMATE SCALE 24 Mi.

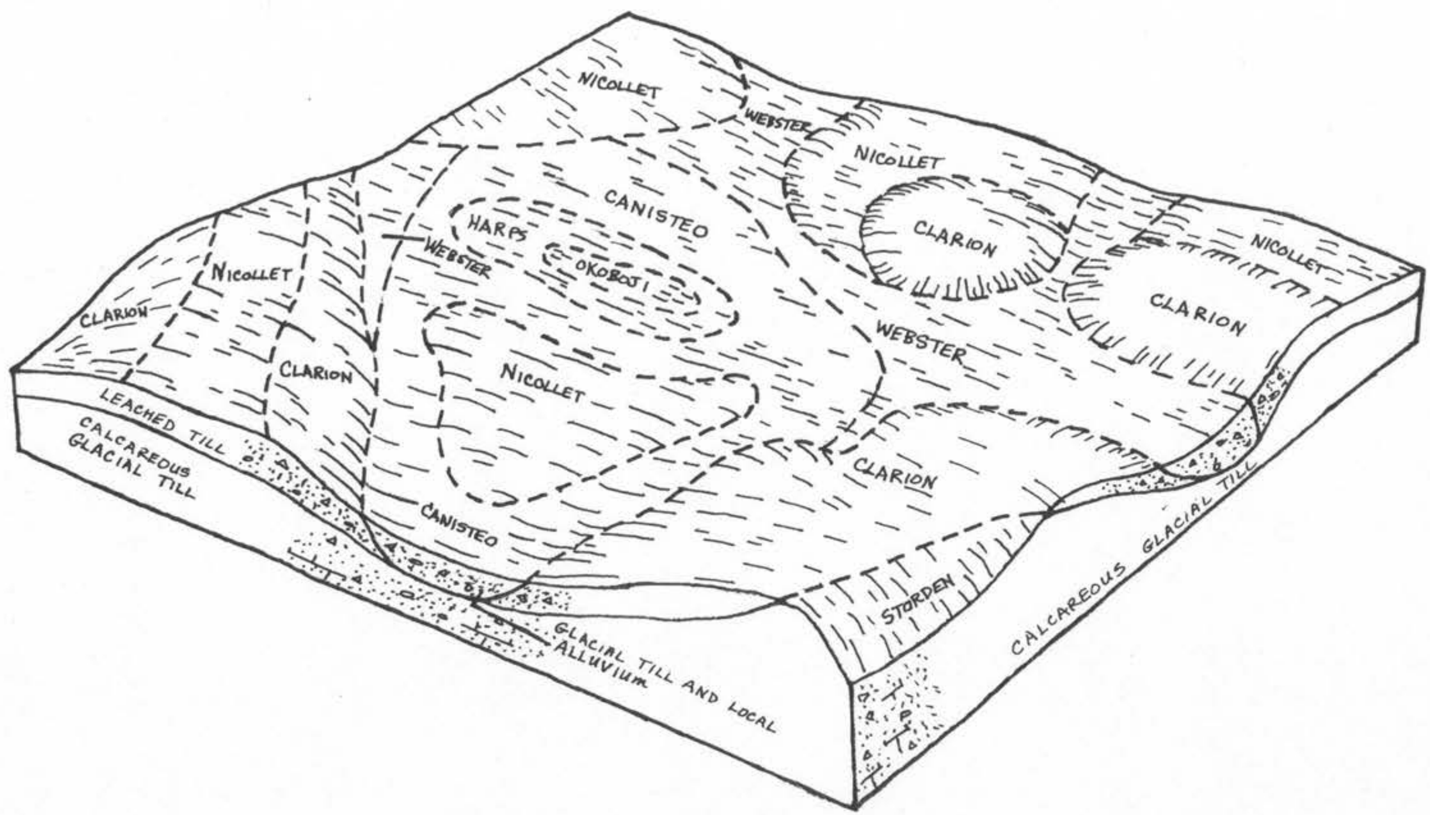

Figure 8. Relief and parent material of soils in the Clarion-Nicollet-Webster association

and on short slopes of the ridges which rise above the upland plain. Clarion soils are primarily on slopes of 2 to 9 percent in the study area. Clarion soils are well-drained and developed from glacial till. The surface layer is generally very dark brown loam about 9 to 14 inches thick.

The Nicollet soils occur on low rises and the lower parts of gentle slopes below the Clarion soils. Slopes are 1 to 3 percent. Nicollet soils are somewhat poorly drained and formed in glacial till. The surface layer is typically very dark brown or black loam or clay loam about 15 to 20 inches thick.

Webster soils occur in swales and nearly level areas on the low lying upland plain. Slopes are 0 to 2 percent. Webster soils are poorly drained and formed in glacial till or sediments from glacial till. The surface layer is black silty clay loam about 15 to 20 inches thick.

Canisteo soils are in similar landscape positions and have similar characteristics to the Webster soils. The distinguishing characteristic between the two soils is that the Canisteo is calcareous and the Webster is not calcareous.

Minor soils include the very poorly drained Okoboji soils in the saucer-like depressions and the poorly drained Harps soils on rims around the depressions. When dry the Harps soils are very light in color due to the high concentration of carbonates on the surface.

Buchanan County Area

The Buchanan county study sites are located in a two-mile wide flight line following highway 150. It stretches the entire length of the county. The crosshatched area in Appendix B shows the area.

The topography in this area is generally nearly level to gently sloping. It is composed of low swells which rise between intervening swales. The three major soils on the landscape in this association are the Kenyon, Floyd and Clyde soils with a few minor soils (Figure 9).

Kenyon soils generally occur on slopes of 2 to 5 percent although their occurrence on 1 to 15 percent is not uncommon. They are moderately well-drained and occur on convex ridges and swells on the gently sloping upland. They formed in two-story parent material, and loamy sediment overlying loam-textured glacial till. The surface layer is a dark brown loam.

Floyd soils are on concave lower slopes and at the upper end of drainageways. Slopes are generally 1 to 5 percent. They formed from local alluvium over glacial till and are somewhat poorly drained. The surface layer is a black loam.

The Clyde soils occur on slopes of 0 to 2 percent in the upland drainageways. The Clyde and Floyd soils may occur as a complex in mapping. Clyde soils formed in local alluvium over glacial till. They are poorly drained and have a black

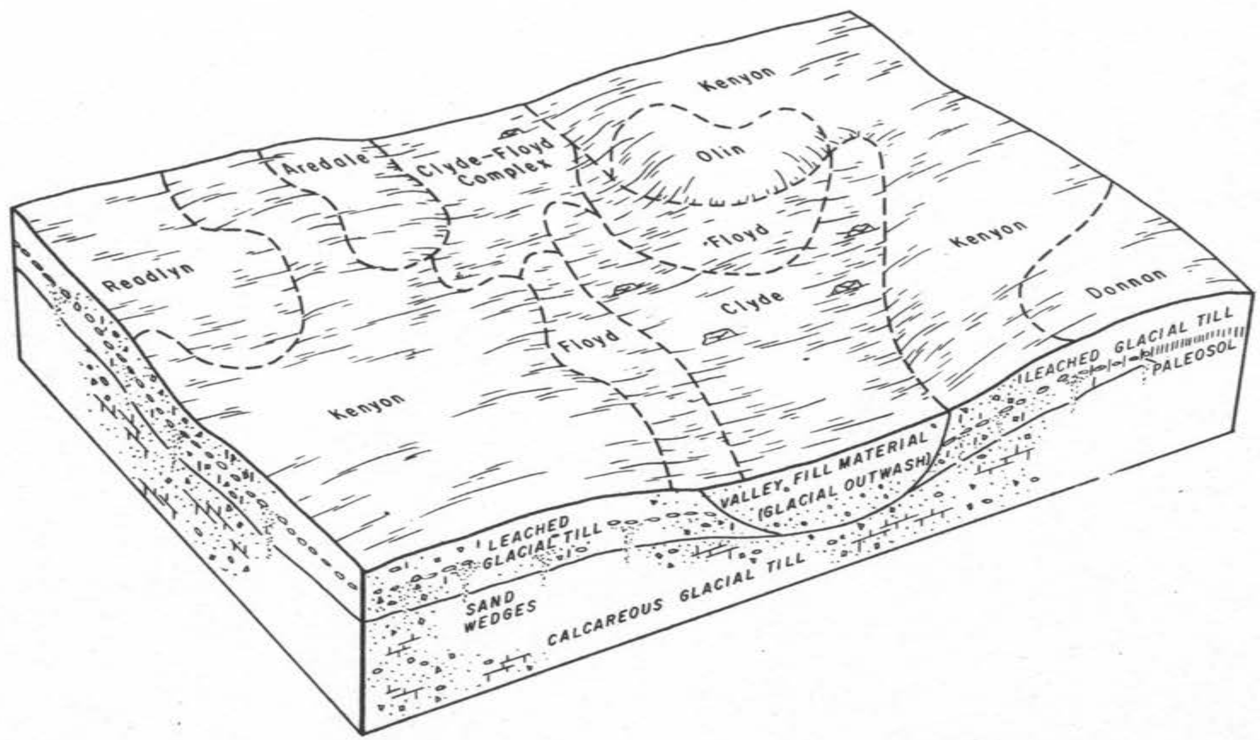

Figure 9. Relief and parent material of soils in the Kenyon-Floyd-Clyde association

silty clay loam to clay loam surface layer.

Some other minor soils located in the area are Sparta, Dickinson and Olin soils. They formed in sandy parent material. These soils generally have a very dark brown surface layer with textures of sandy to sandy loam.

Lyon County Area

The Lyon county study sites are located in a two-mile wide flight line following highway 75. It stretches from highway 27 south to the Sioux county line. The crosshatched area in Appendix B shows the area.

The topography in this area is generally gently sloping to moderately sloping. A few areas along major streams are strongly sloping to steep.

The four primary soils on the landscape in the association are the Galva, Primghar, Sac and Marcus soils (Figure 10).

In this area, loess blankets most of the uplands. It covers the broad upland flats and ridges and extends down the sideslopes. This loess ranges in thickness from 3 to 15 feet and covers glacial till of loam and clay loam textures. This till outcrops near the base of some of the sideslopes.

The Galva soils occur on slightly convex ridges and sideslopes. Slopes are generally 2 to 5 percent but may be as steep as 15 percent. Galva soils are well-drained and

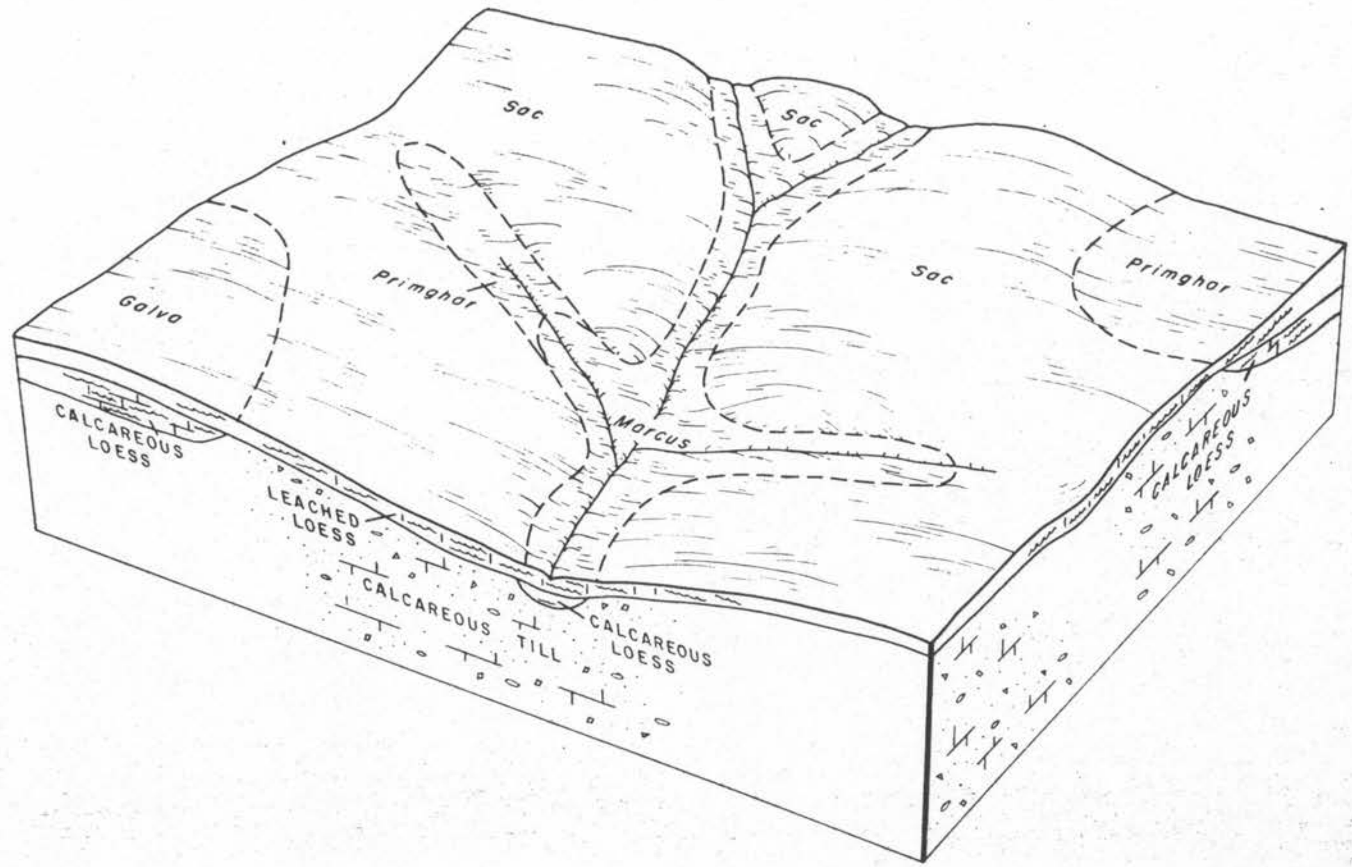

Figure 10. Relief and parent material of soils in the Galva-Primghar-Sac association

formed in loess greater than 40 inches thick overlying glacial till. The surface layer is generally a very dark brown silty clay loam.

The Primghar soils occupy very gentle slopes of 1 to 3 percent, but range to 5 percent. They are moderately well to somewhat poorly drained. Slopes may be either slightly convex or slightly concave. Primghar soils formed in loess greater than 40 inches thick overlying glacial till. The surface layer is typically a black silty clay loam.

The Sac soils occur at the bases of sideslopes. Slopes are typically 2 to 5 percent but may range to 14 percent. They are well-drained and formed in 20 to 40 inches of loess overlying glacial till. The surface layer is generally a very dark brown silty clay loam.

The Marcus soils are poorly drained and occur on level or nearly level slopes of 0 to 2 percent. They are in slightly concave positions at heads of drainageways or on broad upland flats. They formed in loess greater than 40 inches thick overlying glacial till. The surface layer is typically a black silty clay loam or silty clay.

These study sites are widely distributed across the state and involve soils formed from several different parent materials. Cropping patterns vary widely between these areas. Because of the great variability of these characteristics, this study should present an accurate idea of the usefulness of the various types of imagery across the state of Iowa.

METHODS OF STUDY

Acquiring Imagery and Collecting Data

Five types of imagery were acquired in this study to determine the advantages and disadvantages each might have for use in soil mapping. They were panchromatic black and white, color, color infrared, multispectral and thermal infrared. Only three of the five were analyzed in detail. After visually comparing the color with the color infrared, it was decided that the color appeared to yield no more information than did the color infrared. The multispectral imagery only verified what other researchers (Tanguay et al., 1969) have found; that the red band (0.62 to 0.66 microns) and the green band (0.52 to 0.55 microns) showed the greatest soil contrasts.

The first flight to obtain the color infrared and thermal infrared imagery used in this study was on May 5, 1973, but due to a malfunction of the thermal scanner, a second flight had to be flown on May 15, 1973. Weather conditions at the time of flight were clear on both days. Both flights were flown between 11:00 am CDT and 1:00 pm CDT.

The color infrared imagery for Boone county was acquired at an altitude of 8000 feet and the thermal infrared imagery at an altitude of 10,000 feet. In Buchanan and Lyon counties the color infrared data was obtained at 5000 feet.

No thermal infrared imagery was acquired in these two counties. The panchromatic black and white imagery used is Agricultural Stabilization and Conservation Service (ASCS) photographs. The black and white imagery in Boone county was acquired on May 20, 1958. In Buchanan county, it was acquired on June 4, 1972. And in Lyon county, it was acquired on August 8, 1962.

A RC8-2 camera using Kodak 2443 film and a 12 AV filter was used to obtain the color imagery and a RS14 thermal scanner using Kodak 2498 film was used to obtain the thermal infrared imagery.

Rainfall data for each day was recorded for a period of 10 days prior to the day the imagery was acquired. This was obtained from the nearest weather station. Also, because thermal infrared imagery was obtained in Boone county, the minimum and maximum temperatures were recorded at the same time (Table 2).

At the Boone county study area, additional data were collected on the ground temperature and percent moisture of the surface layer to a depth of 1 to 2 inches. This data were taken within known soil bodies. It is presented in Table 3. Also included in this table is the time of day the sample was collected, the soil map unit located at that site, the aspect of the slope, if any, and the field condition at the time of sampling.

Table 2. Temperature and rainfall at study sites

Date	Rainfall (inches)	Temperature Min.	Temperature Max.
	BOONE COUNTY		
April 26	0	40	60
April 27	0	34½	56
April 28	0	34	62
April 29	0	51	77
April 30	0.65	49	72
May 1	0.45	52	62
May 2	0.55	30½	54½
May 3	0	33	60
May 4	0	35	67
May 5	0.14 (8:30a.m.- 10:30a.m.)	50	66
	BUCHANAN COUNTY		
April 26	0		
April 27	0		
April 28	0		
April 29	T		
April 30	0.09		
May 1	0.55		
May 2	0.33		
May 3	0		
May 4	0		
May 5	0		
	LYON COUNTY		
April 26	0		
April 27	T		
April 28	0		
April 29	T		
April 30	T		
May 1	0.64		
May 2	0.10		
May 3	0		
May 4	0		
May 5	0		

Table 3. Boone county soil moisture test data

Observation Point	Soil Map Unit	Temp C°	% Moisture
1	90	14.5	42.88
2	95	14.0	19.29
3	107	17.0	36.13
4	138B	16.0	18.59
5	138B	14.6	14.62
6	138B	16.3	15.74
7	138C2	16.5	11.05
8	90	15.0	33.51
9	138B	14.9	19.68
10	138B	13.1	13.12
11	107	14.2	27.30
12	138B	12.8	18.47
13	107	14.6	32.51
14	138B	14.9	16.68
15	138B	13.0	19.97
16	55	13.9	23.22

Observation Point	Time of Day	Soil Map Unit	Aspect	Field Condition
1	12:10p.m.	90	--	spring plowed
2	12:12p.m.	95	east	spring plowed
3	12:15p.m.	107	east	spring plowed
4	12:18p.m.	138B	north	spring plowed
5	12:22p.m.	138B	east	spring plowed
6	12:25p.m.	138B	east	cornstalks unplowed
7	12:30p.m.	138C2	west	fall plowed
8	12:35p.m.	90	--	new seeding (bare)
9	11:55a.m.	138B	south	oats (3" high)

Table 3 (Continued)

Observation Point	Time of Day	Soil Map Unit	Aspect	Field Condition
10	11:58a.m.	138B	north	spring plowed
11	12:02p.m.	107	--	spring plowed
12	12:05p.m.	138B	south	spring plowed
13	11:40a.m.	107	--	spring plowed
14	11:43a.m.	138B	--	spring plowed
15	11:46a.m.	138B	east	spring plowed
16	11:50a.m.	55	north	spring plowed

To obtain the moisture content, the samples were collected and placed in airtight containers. They were immediately taken to the laboratory and approximately a 20 gram sample was taken. These samples were then placed in an oven to dry for 24 hours and were again weighed. The water loss was recorded and from this the percent moisture of the sample was calculated.

Standard soil survey maps prepared by experienced soil scientists in the progressive soil survey program were used as ground truth for this study.

In the preparation of these maps a trained soil scientist covers the area thoroughly examining the various surface and subsurface properties of the soil. He then delineates the different soil map units based on these properties on a black and white aerial photograph. When delineating these boundaries, the soil scientist uses all the clues he can see on the photographic image and the landscape as he looks across it. This enables him to more accurately place the soil boundaries.

Analysis of Imagery and Data

In analyzing the imagery for its possible use as a soil survey tool, soil boundaries were delineated using three methods of analyses. They were (1) stereoscopic viewing of both the color infrared and black and white imagery, (2) visual observation of the color infrared, black and white and thermal infrared imagery, and (3) use of a Digicol I^2S color additive viewer in delineating soil boundaries by densities on the color infrared imagery.

Using the visual and stereoscopic viewing, probable soil boundaries were delineated on the color infrared imagery at four randomly selected sites in the Buchanan and Lyon county study area, and on both the black and white and color infrared imagery at five randomly selected sites in the Boone county study area. These soil boundaries were placed on clear acetate paper with each site being a research map. Each research map covers an area 160 acres in size. A clear plastic dot grid with a pattern like the one in Figure 11 was placed over each 160 acre map. Sixteen evenly distributed dots were chosen to be used as the point at which the reading of the drainage class on each map was to be taken. Each dot, then, represented 10 acres.

The standard soil survey maps used as the ground truth for this study had each map unit represented by special numbers and letters which indicates the soil series, the slope and the erosion class if the soil is eroded. Appendix A contains examples of standard soil survey maps. For this study, each of these symbols were converted to the corresponding drainage class by using the proper conversion legend for the respective counties (Tables 4, 5, 6).

A numerical value was assigned to each natural soil drainage class to simplify the analysis of the data recorded (Table 7). The reason the excessively drained and somewhat excessively drained drainage classes were grouped together is that they both appear as very light areas on the photographs.

The standard soil survey maps and the research maps were placed under the dot grid and the numerical values at each point were recorded. If a point fell on a soil line then both values were recorded, but the value of the area into which the dot fell closest was circled and counted as the correct value.

The other method employed in this study was the use of

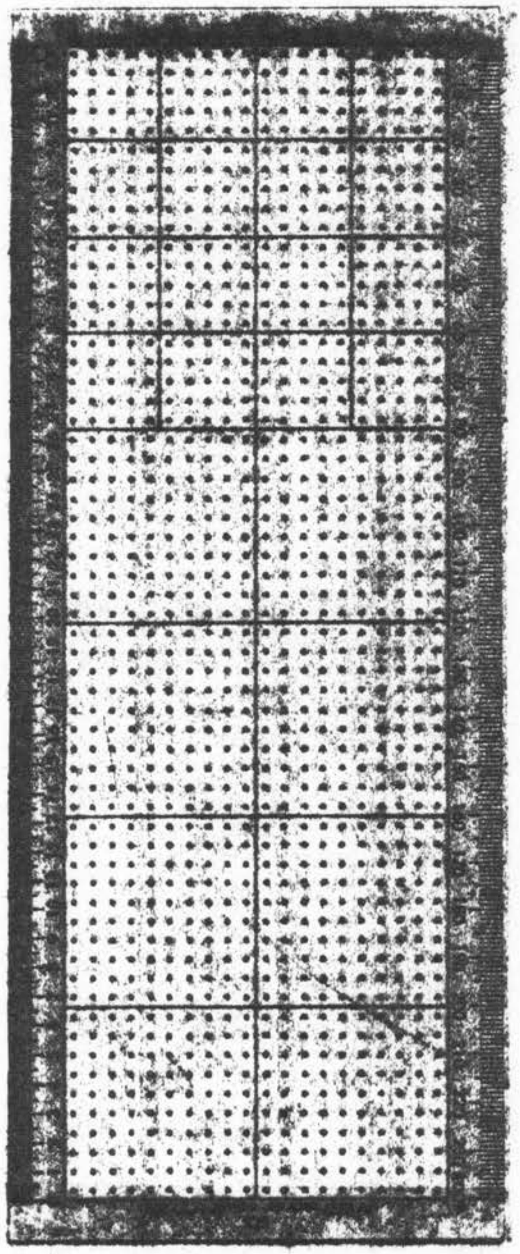

Figure 11. Pattern of plastic dot grid

Table 4. Conversion legend for Boone county

State No.	Series	Drainage	Surface Color
55	Nicollet loam	SP	10YR2/1
138	Clarion loam	WE	10YR2/1
107	Webster silty clay loam	P	N2/0
507	Canisteo silty clay loam	P	N2/0
90	Okoboji mucky silty loam	VP	N2/0
95	Harps loam	P	10YR2/1
6	Okoboji silty clay loam	VP	N2/0

Table 5. Conversion legend for Buchanan county

State No.	Series	Drainage	Surface Color
41	Sparta loamy fine sand	E	10YR2/2
408	Olin fine sandy loam	W & SE	10YR2/2
725	Hayfield loam	MW & SP	10YR3/1
175	Dickinson fine sandy loam	W & SE	10YR2/2
83	Kenyon loam	MW & W	10YR2/1
84	Clyde silty clay loam	P & VP	N2/0
391	Clyde-Floyd complex	Complex	
152	Marshan clay loam, deep	VP & P	N2/0
221	Palms muck	VP	10YR2/1
198	Floyd loam	SP	10YR2/1
407	Schley loam	SP	10YR2/1
399	Readlyn loam	SP	10YR2/1
398	Tripoli silty clay loam	P to SP	N2/0

Table 6. Conversion legend for Lyon county

State No.	Series	Drainage	Surface Color
70	McPaul silt loam	WD & MWD	10YR3/2
410	Moody silty clay loam	WD	10YR3/2
92	Marcus silty clay loam	P	N2/0
310	Galva silty clay loam	WD	10YR2/2
133	Colo silty clay loam	P	10YR2/1
91	Primghar silty clay loam	SP	10YR2/1
878	Ocheyedan loam	WD	10YR2/1
174	Bolan loam	WD	10YR2/2
25	Chute loamy fine sand	E	10YR4/3
27	Terril loam	MWD	10YR2/1
910	Trent silty clay loam	MWD	10YR2/1

Table 7. Numerical rating for each natural soil drainage class

Class	Rating
Excessively Drained and Somewhat Excessively Drained	1
Well-Drained	2
Moderately Well-Drained	3
Somewhat Poorly Drained	4
Poorly Drained	5
Very Poorly Drained	6

the Digicol I^2S color additive viewer. This viewer can separate densities on a transparent photograph of a soil area. It can distinguish to .05 density units. A density unit is ($\frac{1}{\log}$ transmittance to base 10). While the human eye can discern 100 times better than the Digicol viewer, the human eye is discriminating. That is it is constantly comparing one density with another. When the human eye looks at a photograph then it may be able to distinguish between two densities of the same value depending on what is surrounding these areas. The Digicol is nondiscriminating. Therefore, it measures and records only the actual densities as they appear on the photograph.

After these densities have been measured different colors can be assigned to each density. Density levels can also be combined and a color assigned to the combined levels. After the colors have been assigned an image representing the various densities can be displayed on a viewing screen. The resulting image looks very much like a colored map.

The color infrared photograph of each of the sites was analyzed using the Digicol viewer. Photographs were taken of the images displayed on the viewing screen and were visually compared to the corresponding area on the standard soil survey map.

RESULTS AND DISCUSSION

Visual and Stereoscopic Viewing Analysis

Three types of imagery, black and white, color infrared and thermal infrared, were evaluated by visual observation in the Boone county study area. Only the color infrared and black and white imagery were evaluated using stereoscopic viewing in Boone county. In Lyon and Buchanan counties only the color infrared imagery was evaluated. It was evaluated both visually[1] and using stereoscopic viewing.

The thermal infrared imagery was not available in the Lyon and Buchanan county study areas. The black and white ASCS imagery was available in these two areas but the scale was much too small to be of practical use in this study.

Copies of the standard soil survey maps and the research maps are located in Appendix A. The color infrared imagery and thermal imagery from which these maps were prepared is available for additional study and comparison. This imagery is available through the Agronomy or Forestry Departments at Iowa State University.

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[1]Visual or visually in this thesis always refers to the viewing of the imagery without the aid of any mechanical equipment.

Boone county study area

Site 1 is located in the NW¼ of sec. 11, T.83N., R.25W. Table 8 shows the drainage class by numerical ratings at each observation point on the maps made using the various types of imagery. Using only visual observation on the color infrared imagery resulted in seven correct observations out of a possible 16. Two of the observations, 9 and 13, were in a borrow area where the soil profile had been destroyed by removing a large amount of soil. Two other observations, 2 and 3, were field checked because on all methods used to interpret the two types of imagery the same drainage class was observed, but this drainage class did not agree with the standard soil survey map. One of these observations, 3, agreed with the control map, and the other observation, 2, with the research maps. Observation point 7 was interpreted as a well-drained soil on the color infrared map but as a somewhat poorly drained soil on the control map. The image on the photo was masked by a strip of unplowed soil that had corn stalks on it. This masked the soil related tone on the image. The same reason can be given for observation point 8. It was recorded on the research map as a somewhat poorly drained soil and on the control map as a well-drained soil. In sample 14 a somewhat poorly drained soil was again recorded on the research map and a well-drained soil was shown on the control map. The color infrared map

Table 8. Site 1; Boone county (NW¼, Sec.11, T.83N., R.25W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From:			
		Color I.R.	Stereo Color I.R.	Black and White	Stereo Black and White
1	5-2[b]	2	2	2	2
2	2	4	4	4	4
3	5-2	4-5	4	4	4
4	5	5-6	5	5	6
5	5	4	5-2	5	5
6	5-6	5	5	5-6	5
7	4	2	5	5	5
8	2	4	2	5	4
9	5	NA[c]	5	5	5
10	2	2	2	2	2
11	5	5	5	5	5
12	2	4-2	2	2	2
13	2	NA	2	5	2
14	2	4	2	2	2
15	2	2	2	5	2
16	5	5	5	5	5
Total	52	52	57	66	60
Average Drainage Class	(3.25)	(3.71)	(3.56)	(4.12)	(3.75)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

[c]The points designated NA were unable to be classified because of some feature that caused the soil pattern observable on the photograph to be masked.

did appear to have a darker tone associated with this point, but the author believes this tone only appeared to be darker because it occurred next to a very light spot on the imagery.

When the stereoscopic viewing was used on the color infrared imagery, there were many more correct observations. This is because when using the stereoscope tonal changes are not the only criteria used to plot soil boundaries. The stereoscope enables the user to also see the topography or relief of the area. Highs and lows on the landscape can be seen and related to soil drainage classes thus achieving greater accuracy. By using the stereoscope there were 14 correct observations out of a possible 16.

In interpreting the black and white imagery without the aid of the stereoscope, there were 11 correct observations out of 16. At observation points 3, 8, 13 and 15 the research map indicated that the soils were more poorly drained than did the control map. At all of these points, except number 3, the soils and their associated tones were masked by vegetation. When stereoscopic viewing was used to analyze the black and white imagery there were 12 correct observations.

Based upon the results of this study site vegetation or rather the lack of it is very important to correct photographic interpretation for soil information. The effects of the presence of vegetation are just as great with color infrared as with black and white imagery at this study site. The use of stereoscopic viewing improves a soil scientist's ability to more accurately plot soil boundaries at this study site. Better results were obtained using stereoscopic viewing on the color infrared imagery.

If all methods were combined there would be 14 correct observations. Therefore, at this study site there would be no improvement over using only stereoscopic viewing of the color infrared imagery. An example of the color infrared imagery of this site is shown on Slide 1.

Study site 2 is located in the SE¼ of sec. 9, T.83N., R.25W. Table 9 shows the results of the analysis of the various types of imagery. Without the aid of stereoscopic viewing more correct observations were made using the black and white imagery than using the color infrared. Thirteen correct observations were made using the black and white imagery and only seven using the color infrared. Four of the wrong observation points, numbers 3, 4, 11 and 15, fell on a soil line between the incorrect drainage class and the drainage class that agreed with the control map. However, they were closer to the side of the line next to the wrong observation so they were recorded as incorrect.

When the use of the stereoscope was employed on the two types of imagery, there were nine correct observations using the color infrared imagery and 13 correct observations using

Table 9. Site 2; Boone county (SE¼, Sec.9, T.83N., R.25W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.	Black and White	Stereo Black and White
1	4	5	4	4	2
2	5	5	5	5	5
3	5	5 - 4[b]	5	5	5
4	2 - 5	2 - 5	2 - 5	5	5
5	5	5	4	4	5
6	5	5	5	5	5
7	5	4	5	5	5
8	2	2 - 5	2	2	2
9	5	5	5	5	5
10	4	5	2 - 4	2	4
11	2	5 - 2	2	2	2
12	5	5	5	5	5
13	4	4	2	5	2
14	4	5	5 - 4	4	4
15	5	5 - 2	2	5	4
16	5	4	4	5	5
Total	70	67	59	68	65
Average Drainage Class	(4.37)	(4.18)	(3.68)	(4.25)	(4.06)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

the black and white. Two observation points (13 and 15) on the color infrared imagery were off by three drainage classes. They were recorded as well drained on the research maps and poorly drained on the control map. They appeared to be highs on the landscape when viewed through the stereoscope. The author has no explanation for this. The same thing occurred at two observation points (1 and 13) on the black and white imagery.

When all methods of analysis and imagery were used in combination, all 16 observations could be correctly identified. Therefore, at this study site the use of both color infrared and black and white imagery in combination would yield the most accurate soil information.

Study site 3 is located in the NE¼ of sec. 10, T.83N., R.25N. Table 10 shows the results of the analysis of the two types of imagery. There were 14 correct observations using the black and white imagery and 12 correct observations using the color infrared imagery when both were analyzed without the aid of the stereoscope. On the color infrared imagery two of the observation points (10 and 16) fell on soil lines between the correct and incorrect drainage class. Point 10 was recorded as correct and point 16 as incorrect. Two other observation points (3 and 8) required field checking. Both points were determined to agree with the research map and not the control map. The soil body in which point 8

Table 10. Site 3; Boone county (NE¼, Sec.10, T.83N., T.25W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.	Black and White	Stereo Black and White
1	2	2	2	2	2
2	5	4	4	5	5
3	6	5	5	5	5
4	5	5	5	5	6 - 5[b]
5	5	5	5	5	5
6	2	2	2	2	2
7	2	2	2	2 - 5	2
8	4	2	2	2	2
9	4	5	2	4	2
10	2 - 4	2 - 4	2	2	2
11	5	5	5	5	5
12	5	5	5	5	2 - 4
13	4	5	5	4	4
14	2	2	4	4	4
15	2	2	4	4	4
16	6	6 - 5	5	6	6
Total	61	58	59	62	59
Average Drainage Class	(3.81)	(3.62)	(3.68)	(3.87)	(3.68)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

fell was too small to be delineated at the scale of the standard soil survey map used as the control. Field checking showed that if it could have been delineated it would have been correct so it was counted as a correct observation.

When stereoscopic viewing was used to evaluate the two types of imagery there was 11 correct observations on the black and white imagery and nine correct observations on the color infrared imagery. Wrong observations at points 9, 14 and 15 were recorded on both the black and white and the color infrared imagery. The differences were between well-drained and somewhat poorly drained soils. It must be emphasized that many times the elevation difference between these two drainage classes in this study area is only a few feet. Using the stereoscope it is very difficult to observe this difference.

When both methods of analysis were combined on the two types of imagery 16 correct observations were made. This again indicates that the use of a combination of these methods and types of imagery could result in more accurate placement of soil boundaries.

Study site 4 is located in the SE¼ of sec. 11, T.83N., R.25W. Table 11 shows the results of the analysis of the two types of imagery. In this study site two observation points (1 and 12) on the standard soil survey map fell on

Table 11. Site 4; Boone county (NE¼, Sec.10, T.83N., R.25W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.	Black and White	Stereo Black and White
1	4-5[b]	5	5	2	2
2	2	4	4	2	4
3	5	5-4	5	5-4	5
4	5	5	4	5	4-5
5	2	2	2	NA[c]	5
6	2	2	2	NA	2
7	5	5	5	6-5	5
8	5	5	5	5	5
9	5	2-5	5-2	5	5-2
10	2	4	2	4	2
11	5	5	5	5	5
12	2-5	5	5	5	5
13	5	4	2	5	5
14	5	2-5	5	5	5
15	2	4	4	2	5
16	2	NA	NA	5	4-5
Total	58	64	60	64	66
Average Drainage Class	(3.62)	(4.26)	(4.00)	(4.00)	(4.12)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

[c]The points designated NA were unable to be classified because of some feature that caused the soil pattern on the photograph to be masked.

soil lines. Therefore, in the count of correct observations on the research maps, either of the two possibilities were counted as correct.

Without the aid of the stereoscope there were 11 correct observations using the black and white imagery and nine correct observations using the color infrared imagery. This study site had several areas that had been tilled only a short time before the color infrared imagery was acquired. As a result, many of the tonal patterns on the imagery related to soil map units and drainage classes were masked. For example, at observation points 2, 13, 14 and 15 this was the case. As a result, incorrect observations were made at three of these points. At point 16 on the color infrared imagery and at points 5 and 6 on the black and white imagery vegetation masked the soil pattern and the author was unable to predict the correct soil drainage class.

Using stereoscopic viewing there were ten correct observations with the black and white and 11 correct observations with the color infrared imagery. In this study site it appears that the lack of tonal patterns on the imagery also decreases the usefulness of the stereoscope as evidenced by the wrong observations at observation points 5 and 16 on the black and white imagery. These did not indicate a rise on the landscape that would be associated with a well-drained soil as observed on the standard soil survey map. Field observation showed there was a rise. As a result, on the research map both points were identified as poorly drained.

A combination of the two methods of analysis and the two types of imagery resulted in 14 correct observations. Again, this combination produced more correct observations than any single method of analysis or single type of imagery.

Study site 5 is located in the NW¼ of sec.10, T.83N., R.25W. Table 12 shows the results of the analysis of the two types of imagery. As in study site 4 two observation points on the standard soil survey map fell on a soil line. In the count of correct observations on the research maps, either of the two possibilities were counted as correct.

In both methods of analysis, there were 12 correct observations using the black and white imagery and 11 correct observations using the color infrared imagery. Over one-half of this site was covered by vegetation or corn stalks on the color infrared imagery. On the black and white imagery only a small area in the southeast corner was covered by vegetation.

Observation point 12 on both the black and white and the color infrared imagery shows up as a very light area. Because of this it was interpreted as being a well-drained soil. On the standard soil survey map it is shown as a poorly drained soil. When checked in the field it was a poorly drained soil containing a great amount of carbonates.

Table 12. Site 5; Boone county (NW¼, Sec.10, T.83N., R.25W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From:			
		Color I.R.	Stereo Color I.R.	Black and White	Stereo Black and White
1	5	5	5	5	5
2	5	4	4	5	2-5[b]
3	2-5	5	4-2-5	4	4-5
4	5	5	5	5	2-5
5	5	5	5	5	5
6	2-5	5	5	5	2
7	5	5	5	5	5
8	5	4	4	4	2
9	5	5	5	5	5
10	2	2	2	2	2
11	5	4	2	5	5
12	5	2	4	2	2-5
13	4	5	4	4	5
14	5	5	5	5	5
15	5	5	2	2	2-5
16	2	2	2	2	2
Total	70	68	63	65	61
Average Drainage Class	(4.37)	(4.25)	(3.93)	(4.06)	(3.81)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

As a result of these carbonates, the surface of the soil has a light color and appeared almost white on the imagery.

In study site 5 when a combination of both methods of analysis were used on each type of imagery there was 15 correct observations recorded. As in the other study sites in the Boone county study area this combination of methods and imagery produced the greatest number of correct observations.

As can be seen in the tables for each of these study sites, another figure is presented. This is the average drainage class for each standard soil survey map and for each method used on the two types of imagery. If each number is rounded off to the nearest whole number representing a drainage class, in all cases but one, both types of imagery using both methods of analysis accurately depict the average drainage class for each study site as compared to the standard soil survey map.

Buchanan county study area

Only color infrared imagery was used in this study area because the black and white imagery was at too small a scale to be of practical use. In visual comparison by the author the black and white imagery appeared to be about equal in value to the color infrared in predicting soil boundaries and natural drainage class.

Study site 1 is located in the NW¼, sec.10, T.87N., R.9W. Table 13 shows the results of the two analyses of the color infrared imagery. There were ten correct observations made when the imagery was analyzed without the aid of a stereoscope and 12 correct observations when stereoscopic viewing was used. A combination of the results of both methods produced 13 correct observations.

There are a few small areas of somewhat excessively drained soils in the poorly drained map units in this study site. These are shown by a sand spot symbol. The author did not include them on the standard soil survey map. Observation point 8 is recorded as an area of well-drained or somewhat excessively drained soil using the color infrared but as a poorly drained soil on the control map. The point actually fell within an area indicated on the control map by a sand spot symbol so actually it should be considered as a correct observation. An example of the color infrared imagery of this site is shown on Slide 2.

Study site 2 is in the E½, SE¼ of sec.9, T.88N., R.9W. and the W½,SW¼, sec.10, T.88N., R.9W. Table 14 shows the results of the two analyses of the color infrared imagery. There were six correct observations when the color infrared imagery was visually evaluated and five correct observations when stereoscopic viewing was used. There was an area of vegetation that masked some of the soil patterns. The image on this study site was very dark making it difficult to see

Table 13. Site 1; Buchanan county (NW¼, Sec.10, T.87N., R.9W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.
1	1	1	4
2	2	2	2
3	2	2	2
4	5	5	5
5	2	4	2
6	4	4	4
7	5	5	5
8	5	2	1
9	5	5	5
10	5	4	5 - 1[b]
11	4	1 - 4	1 - 4
12	4	4	4
13	4	4	4
14	1	2 - 4	2 - 1
15	5	1 - 4	4
16	4	4	4
Total	53	58	52
Average Drainage Class	(3.31)	(3.63)	(3.25)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

Table 14. Site 2; Buchanan county (E½, SE¼, Sec.9, T.88N., R.9W. W½, SW¼, Sec.10, T.88N., R.9W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.
1	5	4	2
2	5	2	5-2[b]
3	3	4-2	2
4	5	4	2
5	5	4	4
6	1	1	1
7	5	4	4
8	2	2	1
9	2	2	2
10	5	5	5
11	5	4	2-5
12	3	4	2
13	5	5	5
14	5	4	4
15	3	4	4
16	5-3	5	5
Total	62	56	50
Average Drainage Class	(3.88)	(3.50)	(3.12)

[a]Numerical rating by drainage class is shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

many soil patterns. Many of the observation points in this study site were very close to the correct drainage class delineated on the research map. The author is not sure whether the darkness of the imagery is the result of soil color, moisture or poor quality of the imagery. Whatever the cause, however, it greatly reduced the usefulness of the imagery.

Another reason for the low number of correct observations could be the fact that the author is not experienced in the relationship between observed tonal patterns on the imagery and actual soil patterns on the landscape and the corresponding drainage classes which correlate with those patterns in this study area.

Study site 3 is in the SW¼, sec.15, T.87N., R.9W. Table 15 shows the results of the two analyses of the color infrared imagery. As in the previous study site, the number of correct observations was low. There were five correct observations using only visual observations and six correct observations using stereoscopic viewing. Again, vegetation blocked out a portion of the area and the inexperience of the author in relating the tonal patterns on the imagery to the soil patterns on the landscape resulted in reduced accuracy.

Study site 4 is in the NE¼, sec.9, T.87N., R.9W. Table 16 shows the results of the two analyses of the color

Table 15. Site 3; Buchanan county (SW¼, Sec.15, T.87N., R.9W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From:	
		Color I.R.	Stereo Color I.R.
1	5	5	4 - 5[b]
2	3	4	4
3	3	2	2
4	5	1	2
5	3	4	2
6	5	5	5
7	3	4	5
8	5	1	1
9	3	5	5
10	5	4	2
11	4	5	5
12	5	5	2
13	5	2	5
14	5 - 4[b]	4	2
15	5	5	5
16	4	5	5 - 2
Total	67	61	54
Average Drainage Class	(4.18)	(3.81)	(3.37)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

Table 16. Site 4; Buchanan county (NE¼, Sec.9, T.87N., R.9W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From:	
		Color I.R.	Stereo Color I.R.
	1	1	1 - 5[b]
2	5	5	5
3	2	2 - 4	1
4	5	5	5
5	5	5	5
6	5	5	4 - 5
7	2	4	4
8	3	5	5
9	5	5	5
10	5	4	4
11	2 - 3	1 - 4	5
12	3	4	5
13	2	2	1 - 2
14	5	4	5
15	3	4	2
16	2	2	2
Total	56	61	60
Average Drainage Class	(3.50)	(3.81)	(3.75)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.

infrared imagery. There were nine correct observations using only the visual analysis of the color infrared and eight correct observations when the stereoscope was used. In many places the imagery did not lend itself to accurate predictions about soil characteristics. For example, at observation point 8 the imagery was very dark leading the author to believe it was poorly drained, but the standard soil survey map indicated the soil was moderately well-drained. At point 11 the area was too small to have been delineated on the standard soil survey map making it hard to determine if the research map was correct.

The average natural drainage class is given on each of the tables in this study area. In this study area it appears that the color infrared is reasonably accurate in predicting the overall drainage class for each study site.

Lyon county study area

Only color infrared imagery was used in this study area because the black and white imagery was at too small a scale to be of practical use. Visual comparison by the author indicated that the black and white imagery did not have as much value as did the color infrared in predicting soil boundaries and natural drainage classes. There was a great deal more vegetative cover on the black and white imagery because the imagery was acquired in August when the greatest amount of vegetation is present.

Site 1 is located in the SE¼ of sec.32, T.98N., R.45W. The results of the two analyses of the color infrared imagery are shown in Table 17. There were only five correct observations using only visual analysis and only five correct using the stereoscope. At observation points 13, 14, 15 and 16 the soil patterns were masked by vegetation. When both methods of analysis were combined there were six correct observations. At this study site all of the observation points on the standard soil survey map fell on well drained soils. The author was again not familiar with the study area and the relationship between soil patterns on the landscape and tonal patterns on the imagery. Areas that appeared to be poorly drained and somewhat poorly drained at points 7, 9, 11 and 12 for example, were well drained.

Figure 12 shows a graphic display of the results at this study site. As can be seen there was very little consistency in the interpretation of the imagery. This graph as well as the other graphs in this study area show explicitly that lack of experience in a given area makes it almost impossible to consistently make even reasonably accurate predictions about soil properties and to delineate soil boundaries without examining the area in detail by field observations.

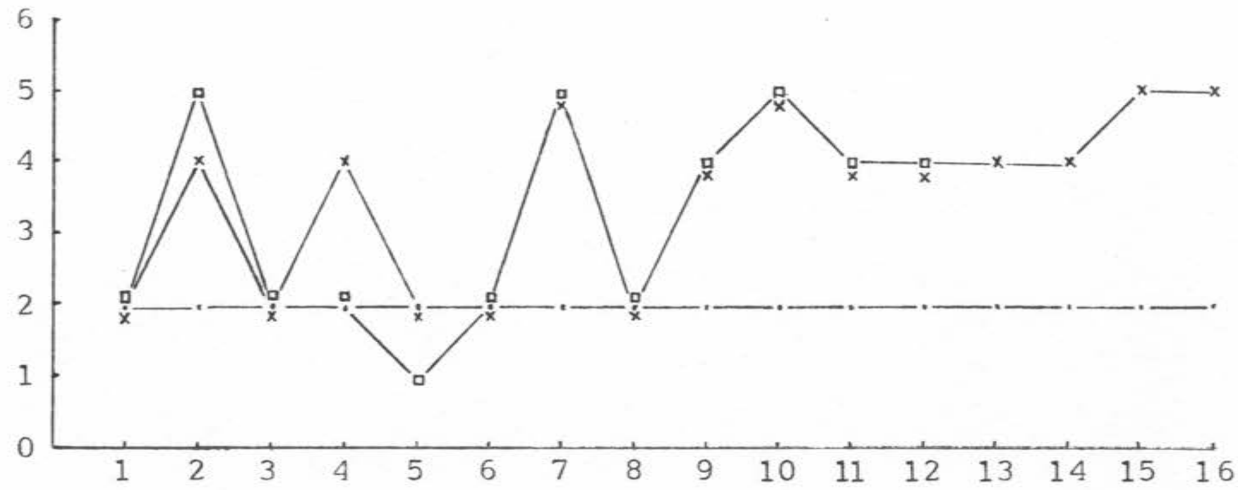
Site 2 is located in the E½ of the SW¼ of sec.33,

Table 17. Site 1; Lyon county (SE¼, Sec.32, T.89N., R.45W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.
1	2	2	2
2	2	4	5
3	2	2	2
4	2	4	2
5	2	2	1
6	2	2	2
7	2	5	5
8	2	2	2
9	2	4	4
10	2	5	5
11	2	4	4
12	2	4	4
13	2	4	NA[b]
14	2	4	NA
15	2	5	NA
16	2	5	NA
Total	32	58	38
Average Drainage Class	(2.00)	(3.63)	(3.16)

[a]Numerical rating by drainage class as shown in Table 7.

[b]The NA here represents an area covered by vegetation so that the soil patterns were obscured.



. Standard Soil Survey Map

□ Color Infrared Imagery viewed without the aid of any mechanical equipment

x Color Infrared Imagery viewed using a stereoscope

Figure 12. Graphic display of site 1 of the Lyon county study area

T.98N., R.45W. and the W½ of the SE¼ of sec.33, T.98N., R.45W. Table 18 shows the results of the analysis of the two methods using color infrared imagery. Using only visual observations there were five correct observations and using stereoscopic viewing there were six correct observations. A combination of the two methods yielded seven correct observations. At this study site all of the observation points except number 9 fell on well-drained soils on the control map. Number 9 fell on a poorly drained soil. The results show that using color infrared this author was not able to consistently or accurately predict soil patterns. A graphic display of the results in Figure 13 for this study site amplify this inconsistency.

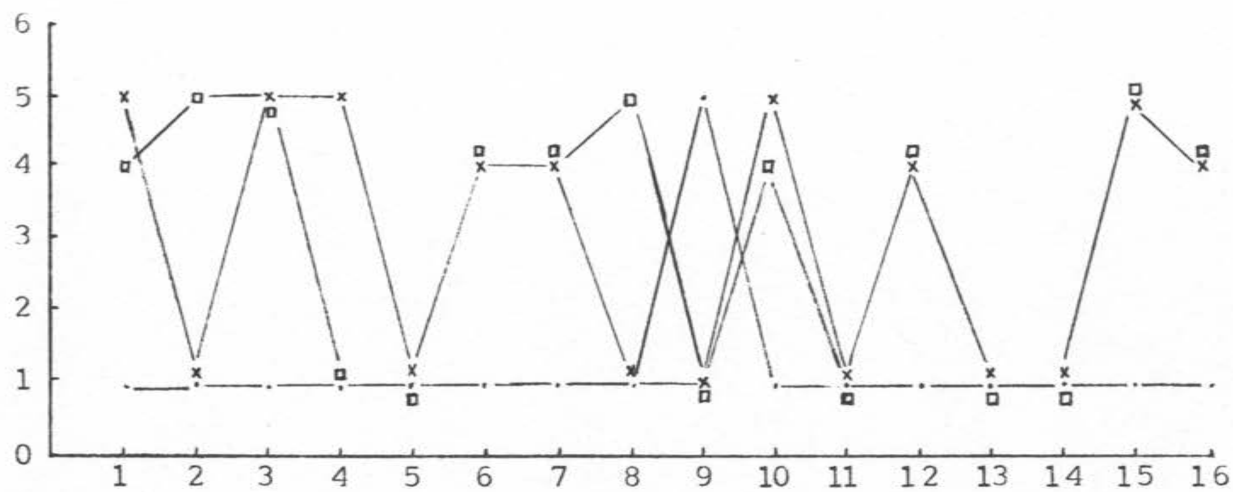
Site 3 is located in the SE¼ of sec.17, T.98N., R.45W. The results of the analysis of the two methods using the color infrared imagery are shown in Table 19 and graphically in Figure 14. There were six correct observations when visually evaluated and eight when the stereoscope was used. A combination of the two methods gave nine correct observations. The lack of experience on the part of the author was the major factor in the poor results obtained at this study site. As in the other study sites in the Lyon county study area, almost all of the observation points on the control map fell on well-drained soils. An example of the color infrared imagery of this site is shown on Slide 3.

Table 18. Site 2; Lyon county (E½, SW¼, Sec.33, T.98N., R.45W. W½, SE¼, Sec.33, T.98N., R.45W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From: Color I.R.	Stereo Color I.R.
1	2	5	4
2	2	5 - 2[b]	5
3	2	5	5
4	2	5	2
5	2	2	2
6	2	4	4
7	2	4	4
8	2	2	5 - 4
9	5	2	2
10	2	5	4
11	2	2	2
12	2	4	4
13	2	2	2
14	2	2	2
15	2	5	5
16	2	4	4
Total	35	55	56
Average Drainage Class	(2.18)	(3.44)	(3.50)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.



. Standard Soil Survey Map

□ Color Infrared Imagery viewed without the aid of any mechanical equipment

x Color Infrared Imagery viewed using a stereoscope

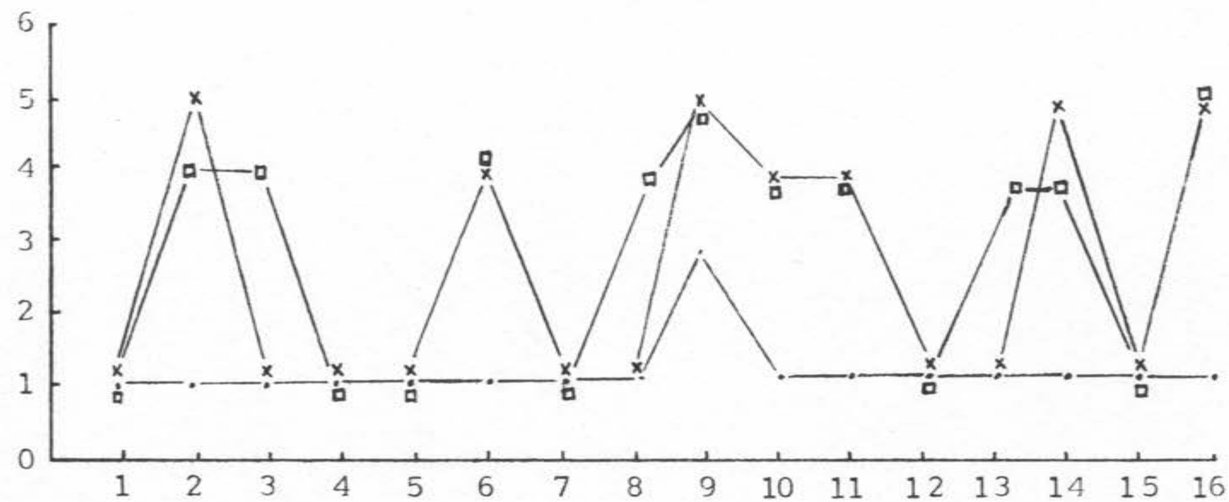
Figure 13. Graphic display of site 2 of the Lyon county study area

Table 19. Site 3; Lyon county (SE¼, Sec.17, T.98N., R.45W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From:	
		Color I.R.	Stereo Color I.R.
1	2	2	2
2	2	2 - 5[b]	4
3	2	2	4
4	2	2	2
5	2	2 - 5	4 - 2
6	2	4	4
7	2	2	2
8	2	2	4
9	3	5	5
10	2	4	4
11	2	4	4
12	2	2	4 - 2
13	2	2 - 4	4
14	3	5	4
15	2	2	2
16	2	5	5
Total	34	50	54
Average Drainage Class	(2.13)	(3.13)	(3.38)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.



- · Standard Soil Survey Map
- ◻ Color Infrared Imagery viewed without the aid of any mechanical equipment
- × Color Infrared Imagery viewed using a stereoscope

Figure 14. Graphic display of site 3 of the Lyon county study area

Site 4 is located in the NE¼ of sec.8, T.89N., R.45W. Table 20 shows the results of the two methods using the color infrared imagery. There were seven correct observations using only visual evaluation and ten when using the stereoscope. A combination of the two methods resulted in ten correct observations. Like the other study sites, almost all of the observation points on the control map fell on well drained soils. Figure 15 shows the results at this study site in graphic form to show the inconsistency of the author in predicting soil patterns and natural drainage classes in this study area.

The average natural drainage class which is shown on each table in this study area for each method used shows that even the general overall drainage class could not be accurately predicted in this study area. On all of the standard soil survey maps this average drainage class was at or near 2.00 indicating a well-drained condition. However using the color infrared imagery it ranged from 3.63 using the stereoscope at site 1 down to 3.06 using the stereoscope at site 4 which indicated a moderately well to somewhat poorly drained condition.

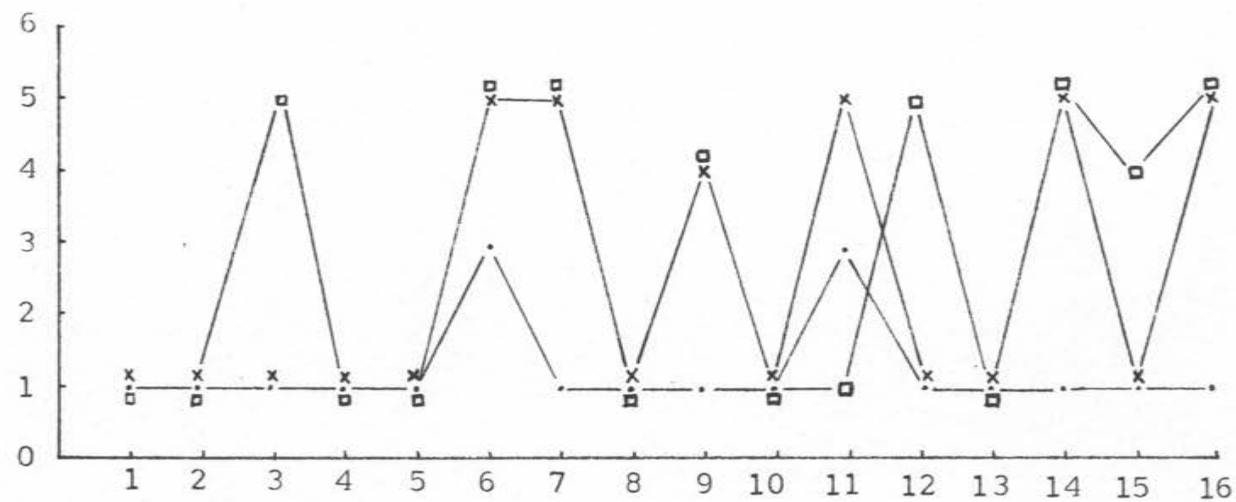
The color of the surface layer is believed to be one of the reasons for the poor results in the Lyon county study area. For example, in all study areas the observation points shown on the research maps as poorly drained appeared as very

Table 20. Site 4; Lyon county (NE¼, Sec.8, T.98N., R.45W.)

Obs. No.	Standard Soil Survey Map	Natural Soil Drainage Class[a] Interpreted From;	
		Color I.R.	Stereo Color I.R.
1	2	2	2
2	2	2	2
3	2	2	5
4	2	2	2
5	2	2	2
6	3	5	5
7	2	5	5
8	2	2	2
9	2	2 - 4[b]	4
10	2	2	2
11	3	5	2 - 5
12	2	4 - 2	5
13	2	2	2
14	2	5 - 2	5
15	2	2 - 4	4 - 2
16	3 - 2	5	5
Total	34	49	54
Average Drainage Clas	(2.13)	(3.06)	(3.38)

[a]Numerical rating by drainage class as shown in Table 7.

[b]This observation point fell on a soil line. The value circled is the value of the area the point came closest to.



- Standard Soil Survey Map

□ Color Infrared Imagery viewed without the aid of any mechanical equipment

x Color Infrared Imagery viewed using a stereoscope

Figure 15. Graphic display of site 4 of the Lyon county study area

dark areas on the imagery. Since the standard soil survey maps indicated it was well-drained or moderately well-drained, there must have been another factor besides soil moisture causing the imagery to appear dark. The author feels this factor could have been the presence of a dark surface layer.

Digicol I^2S Color Additive Viewer Analysis

Each sample site in the three study areas was analyzed using the Digicol I^2S color additive viewer. An explanation of the procedure used was given in the methods of study section. The reason the imagery was analyzed using this method was to determine if important properties of the soil could be identified using the color additive procedure. A soil map based on these properties was displayed on the viewing screen of the Digicol and compared to the control map. Visual comparison was used to determine the accuracy of the Digicol.

Boone county study area

In study site 1 of this study area (Slide 4) the Digicol image showed a definite distinction between the well, somewhat poorly drained soils and the poorly and very poorly drained soils. No excessively, somewhat excessively or moderately well-drained soils occurred in this site. There was no reliable distinction between the well-drained and somewhat poorly drained soils or the poorly drained and very poorly drained soils. In this site two areas showed erroneous data. One was unplowed and covered with cornstalks and the other area had the soil removed for construction of a nearby highway.

In study site 2 (Slide 5), again the grouping of well and somewhat poorly drained soils were delineated from the poorly and very poorly drained soils. There were a few exceptions where they were not delineated but this could be attributed to the fact that the imagery here was darker than the other imagery. A small spot of somewhat excessively drained soil was delineated on this map also.

In study site 3 (Slide 6), a large part of the soil surface was covered with vegetation. There was a pattern discernible in the vegetated area but interpreting it was difficult. There were basically only two drainage classes of soil in this site except for two small areas of somewhat poorly drained soils. The two drainage classes were poorly drained and well-drained. In the soil area without vegetative cover, the Digicol did an excellent job of delineating these two classes.

In study site 4 (Slide 7), when visually viewing the imagery there appeared to be a highly contrasting soil pattern. However, when viewed by the Digicol there was not as much difference in densities as was expected. This is because of the nondiscriminating nature of the machine. In some areas the same two groups of soils as mentioned in the previous sample sites were delineated but in other parts of the map they were not. Overall, this Digicol reproduction was not accurate when compared to the standard soil survey map.

In study site 5 (Slide 8), the Digicol analysis and resulting picture is not as reliable an indicator of the soil drainage classes as the imagery in the first two sample sites. There was a difference in tillage on this study site which resulted in the same reading for soils of different drainage classes. For example the somewhat poorly drained areas were indicated by the same color in one area as the poorly and very poorly drained area in another area. Only a few areas of well-drained soils could be delineated accurately.

<u>Buchanan county study area</u>

In study site 1 (Slide 9), the Digicol was able to delineate small areas shown on the soil map as sand spot symbols in poorly drained areas. Using this method it was also possible to delineate the grouping of excessive and somewhat excessive, well-drained and somewhat poorly drained soils from the poorly drained soils. In a few instances the somewhat poorly drained soils could be separated but not consistently.

In study site 2 (Slide 10), the excessively and somewhat excessively drained soils were accurately delineated from the well and moderately well-drained soils. The well, moderately well and somewhat poorly drained soils however could not be consistently separated from the poorly drained soils.

In study site 3 (Slide 11), there was no consistency in delineating drainage classes using the Digicol.

In study site 4 (Slide 12), there were a few small areas of excessively and well-drained soils distinguished from the rest of the area but according to the machine these appeared to have the same density and it was not possible to tell which was the excessively drained and which was the well-drained soil. There was a great deal of inconsistency in the delineations.

Lyon county study area

In the Lyon county study area a great proportion of the soils were well or moderately well-drained. As a result the Digicol was of very little use in delineating soils based upon the drainage classes. Very little information could be obtained from the Digicol method in this area. Slides 13, 14, 15 and 16 show the imagery as viewed by the Digicol viewer for each respective study site.

SUMMARY AND CONCLUSIONS

Remotely sensed imagery in the form of black and white aerial photographs is used by soil scientists throughout the United States and in many other countries as a base on which to plot soil boundaries. There are now other types of remotely sensed imagery which are available. This imagery could give additional clues as to location of potential soil delineations. Color infrared and thermal infrared imagery are examples of this additional imagery. In this study both of the above types of imagery were evaluated to determine their usefulness as a base on which to delineate soil map units.

Summary of Factors Determining the Usefulness of Imagery for the Project

Several factors determine the usefulness of any of the imagery analyzed in this study for predicting possible soil boundaries and characteristics. The factors determined in this study are summarized below.

(1.) The degree to which tonal patterns on the imagery can be related to soil patterns on the landscape is the first important factor. Without tonal changes in the form of patterns on the imagery, the photograph would be of little value in delineating soil boundaries. Many times the tonal patterns on the imagery do not accurately reflect soil patterns on the landscape, and, therefore, the soil scientist is not able to make efficient use of the imagery. In this study as well as in previous research by others, several causes for the presence of tonal patterns that are not related to soil boundaries were identified.

The first cause is poor quality of the imagery. This could be the result of improper processing of the imagery causing false tones, a faulty camera, or poor film quality. Also improper setting of the camera could result in lowered quality of the imagery.

Secondly, the masking effect caused by the presence of vegetation covering the soil surface is another possible cause. For the purposes of interpreting the imagery for soil survey use, generally the optimum time to acquire imagery is when the greatest amount of bare soil is present on the landscape. Several study sites had areas where the vegetation masked the possible soil patterns on the imagery. Freshly tilled soil also masks the soil patterns of the landscape. Where thick dark surface layers occur, tilling turns up topsoil which, when moist, is often the same color regardless of minor differences in organic matter content. As drying occurs, the differing amounts of organic matter results in differences in the color of the soil. This difference in organic matter also occurs between slightly eroded soils and moderately to severely eroded soils. This is one of the reasons there was inconsistency in predicting possible soil map units in the Lyon county study sites. Most of the soils were well-drained, but there were different amounts of organic matter related to varying degrees of erosion. The tones on the imagery were darker where the organic matter was high. The soils were interpreted on the research maps as being more poorly drained.

(2.) The imagery should reflect landscape characteristics which make stereoscopic viewing possible. When using the stereoscope, tonal changes are combined with other criteria to plot soil boundaries. The stereoscope permits the user to also see the topography or relief of the area. Therefore, highs and lows on the landscape can be seen, and by relating elevation differences to soil drainage greater accuracy can sometimes be achieved. Difference in elevation must be more than 2 to 5 feet for the stereoscope to be most useful.

(3.) The experience and ability of the user in interpreting and relating the tonal patterns on the imagery to the soil patterns on the landscape is a third factor in determining the usefulness of the imagery. The author was experienced in the interpretation of imagery in the Boone county study area only. The experience was gained by working on the standard soil survey of that county for two years prior to initiation of this study. The other two study areas, Buchanan and Lyon counties, were unfamiliar and the relationship of the tonal patterns on the imagery to soil patterns on the landscape was not known. As a result there was poor accuracy in delineating possible soil boundaries and predicting soil characteristics in those two study areas.

Many people believe they can go into an unfamiliar area and using remotely sensed imagery in the form of aerial photographs accurately predict characteristics and properties of the soil based upon their familiarity with another area. As clearly demonstrated by this study, the accuracy of predicting soil characteristics in an unfamiliar area is very low. The results of the Buchanan and Lyon county study areas support this conclusion. However, the Buchanan county results were somewhat better because a few of the soils and soil patterns are similar to those in the Boone county study areas.

Conclusions Based on the Results

Based on the hypothesis that natural soil drainage classes can be interpreted by using aerial photographs and from that a certain sequence of soils can be applied to those drainage classes, the following conclusions can be reached based upon the results of this study. If the user of remotely sensed imagery is going to try even on a large scale to delineate soil boundaries and predict soil characteristics using that imagery, he must be very familiar with the relationship between tonal patterns on the imagery and soil patterns on the landscape. This can be achieved only by study of these relationships in the field.

Based on the results of this study, if the user has a choice of only one type of imagery, black and white imagery appears to be the best choice in the Boone and Buchanan county study areas. Color infrared was the best in the Lyon county study area. The author believes this is because the black and white imagery for Lyon county was acquired in August when the amount of vegetative cover was greatest.

Use of a stereoscope on both types of imagery increased the number of correct observations. This is because the user does not have to rely on tonal patterns alone, but can also use elevation differences as a clue to possible drainage class and soil boundary.

Color infrared imagery would be useful as a supplemental tool for soil survey purposes. When a combination of both the black and white and color infrared imagery was used, the number of correct observations was increased in a number of study sites.

Thermal infrared imagery was not useful in this study as a tool to help delineate soil boundaries. There appears to be only a slight correlation between patterns on the thermal infrared imagery and observed soil patterns on the landscape.

Analysis of the color infrared imagery by the Digicol I^2S color additive viewer was expected to yield detailed information about soil characteristics and to delineate map units based on these characteristics. Results of this study demonstrate that it is not within the capability of the viewer to extract all the information desired from the color infrared imagery used in this study.

Only general patterns could be distinguished by the viewer. Two groups of drainage classes could be delineated with fair consistency. These two groups were the well and somewhat poorly drained soils and poorly and very poorly drained soils. A third group that could be delineated sometimes was the excessively and somewhat excessively drained soils.

Quality of the imagery is the most important factor for predicting soil properties and delineating soil boundaries. Regardless of the method used or the experience of the user in analyzing the imagery, high contrasts in photographic tone and soil patterns on the landscape that can be correlated with tonal patterns on the imagery is necessary for consistently accurate results.

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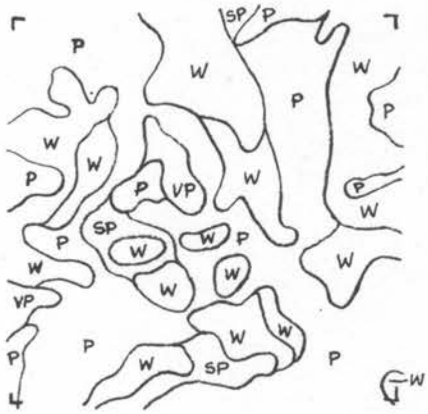
APPENDIX A

Standard Soil Survey Maps and Research Maps

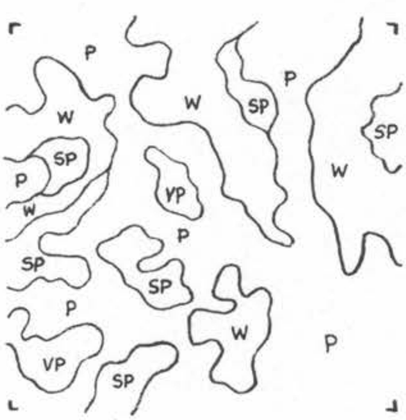
Study site 1

NW¼, sec.11, T.83N., R.25W.   Boone county



Standard Soil
Survey Map

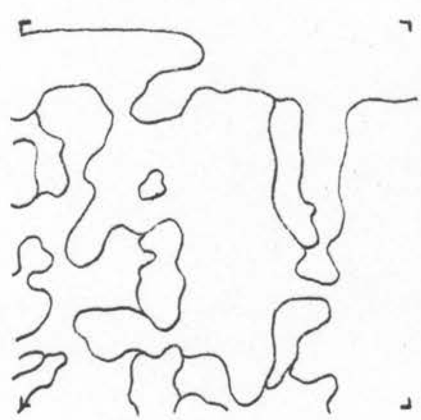
Black and White



Black and White
with Stereoscope

Color Infrared

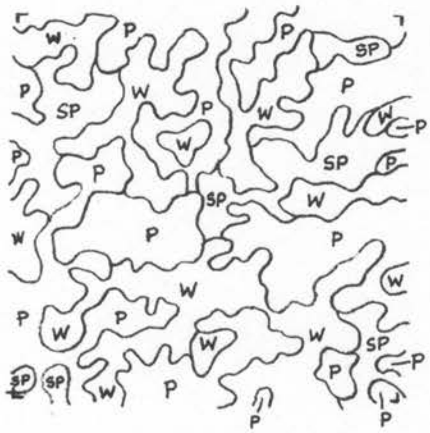
Color Infrared
with Stereoscope



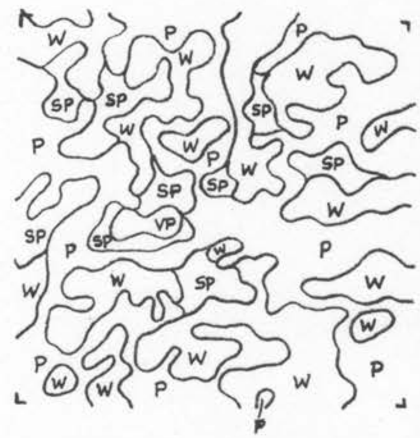
Thermal Infrared

Study site 2

SE$\frac{1}{4}$, sec.9, T.83N., R.25W. Boone county

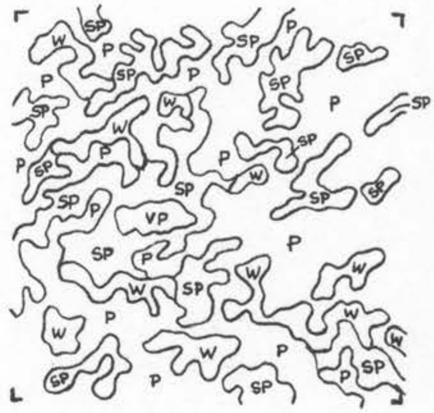


Standard Soil
Survey Map



Black and White

Black and White
with Stereoscope



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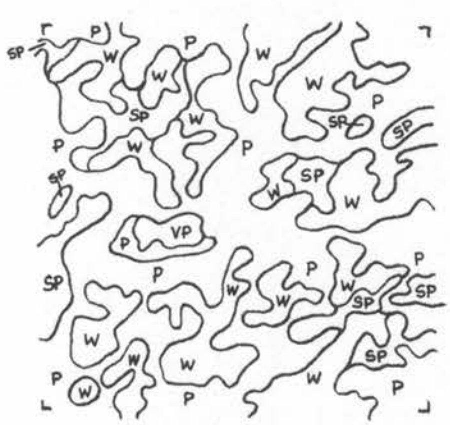
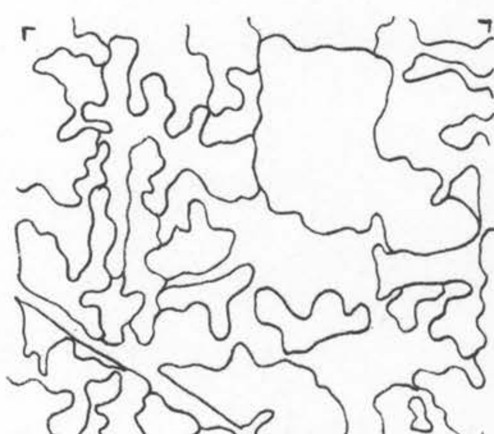


Color Infrared
with Stereoscope

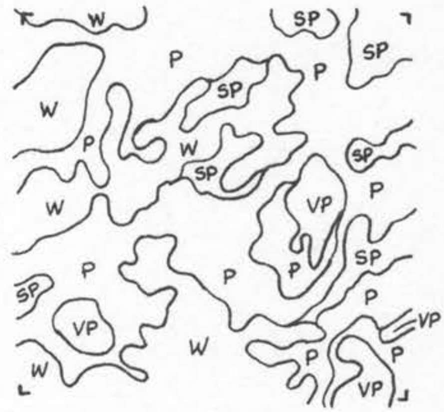


Thermal Infrared

Study site 3

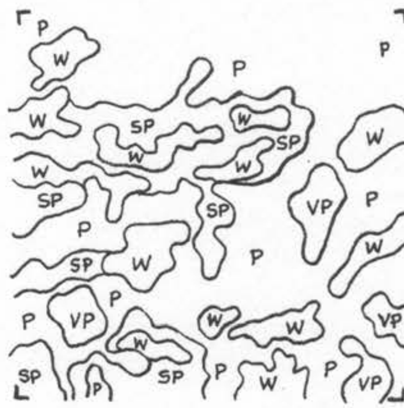
NE¼, sec.10, T.83N., R.25W. Boone county

Standard Soil
Survey Map



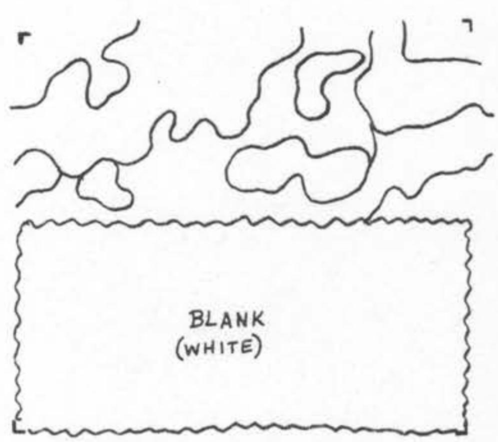
Black and White

Black and White
with Stereoscope



Color Infrared

Color Infrared
with Stereoscope



Thermal Infrared

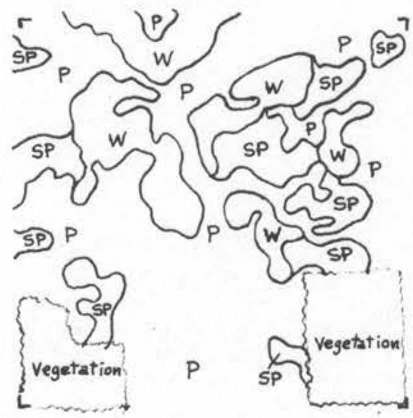
Study site 4

SE$\frac{1}{4}$, sec.11, T.83N., R.25W. Boone county

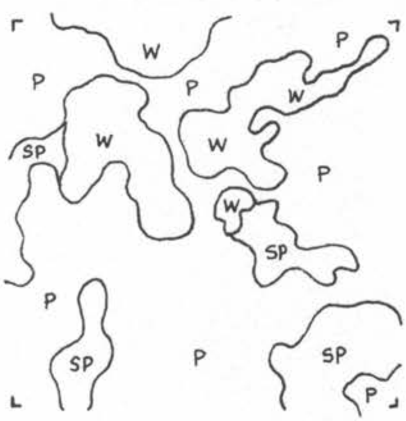
Standard Soil
Survey Map

Black and White

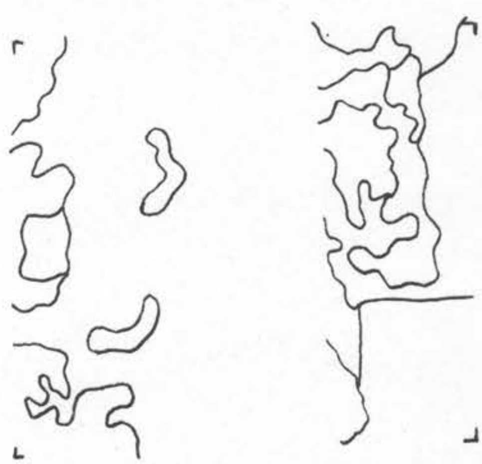
Black and White
with Stereoscope



Color Infrared

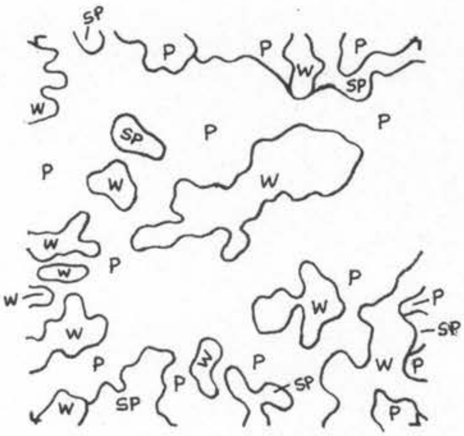


Color Infrared
with Stereoscope


Thermal Infrared

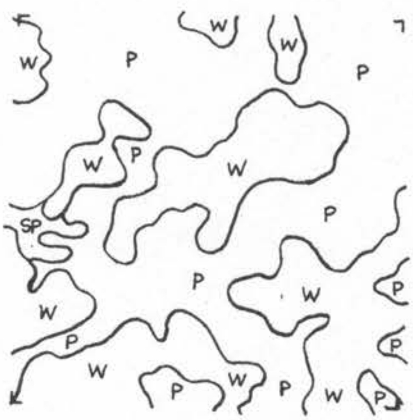
Study site 5

NW¼, sec.10, T.83N., R.25W. Boone county

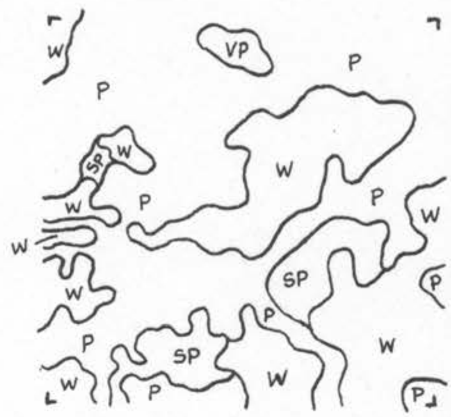


Standard Soil
Survey Map

Black and White



Black and White
with Stereoscope



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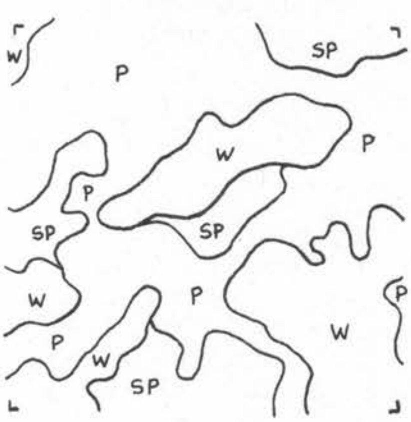
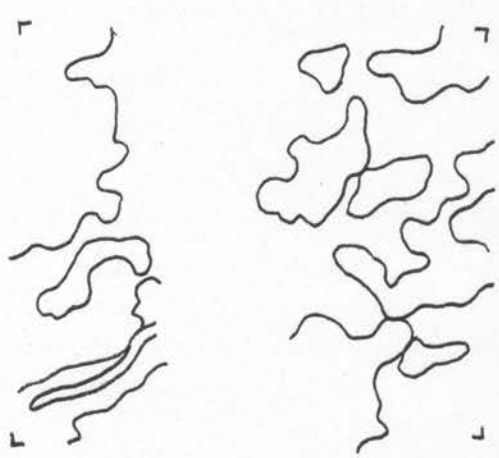
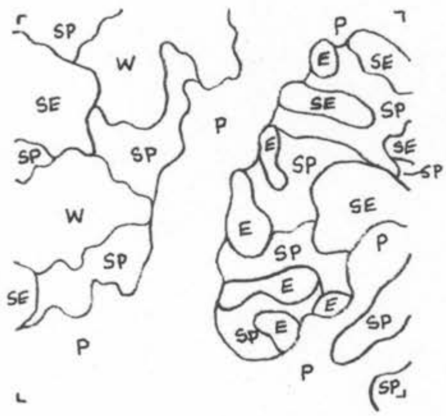


Color Infrared
with Stereoscope



Thermal Infrared



Standard Soil
Survey Map

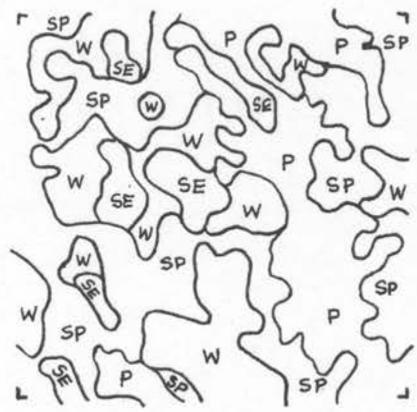
Color Infrared

Color Infrared
With Stereoscope

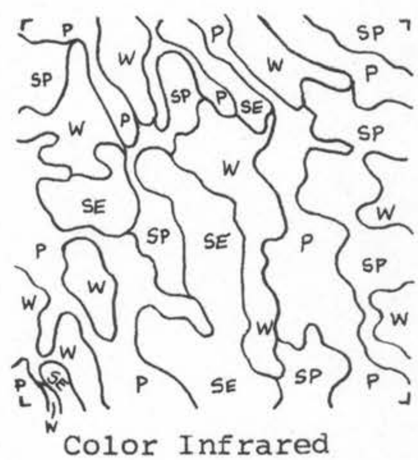
Study site 1

NW¼, sec.10, T.87N., R.9W. Buchanan county

Standard Soil
Survey Map



Color Infrared

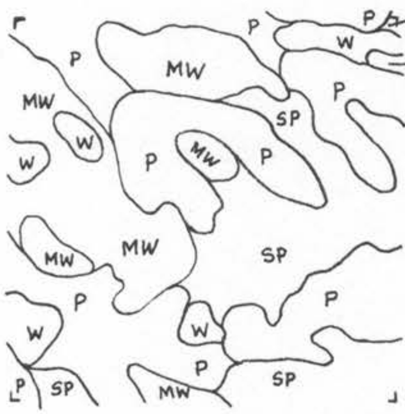


Color Infrared
with Stereoscope

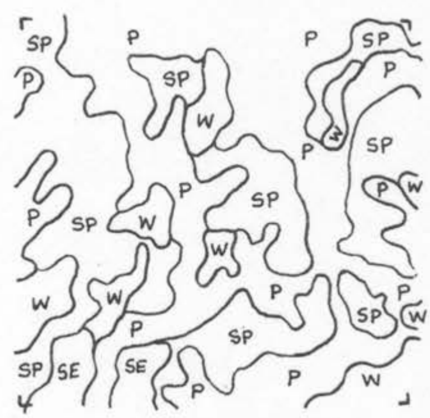
Study site 2

E½, SE¼, sec.9, T.88N., R.9W.
W½, SW¼, sec.10, T.88N., R.9W.

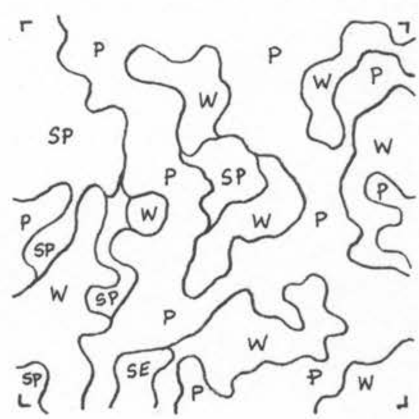
Buchanan county



Standard Soil
Survey Map



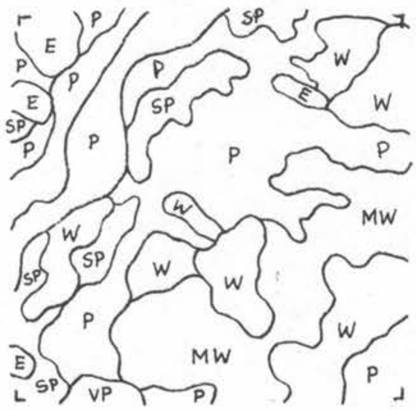
Color Infrared



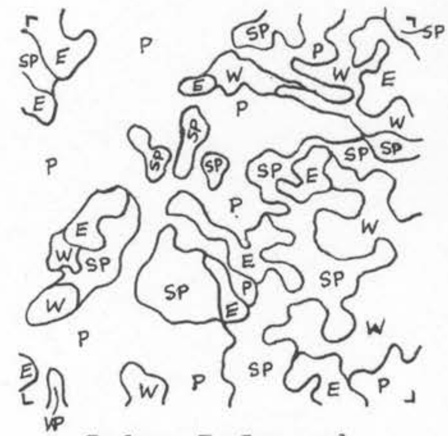
Color Infrared
with Stereoscope

Study site 3

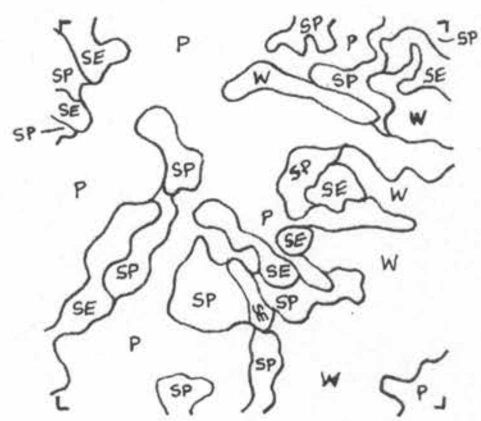
SW¼, sec.15, T.87N., R.9W. Buchanan county



Standard Soil
Survey Map



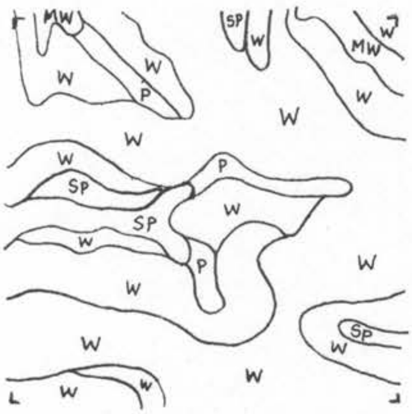
Color Infrared



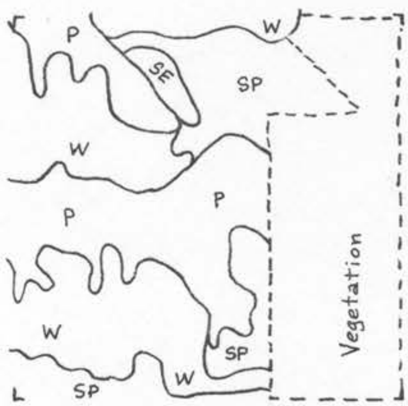
Color Infrared
with Stereoscope

Study site 4

NE¼, sec.9, T.87N., R.9W. Buchanan county



Standard Soil
Survey Map



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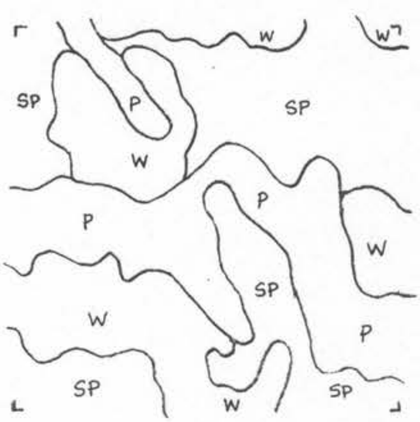
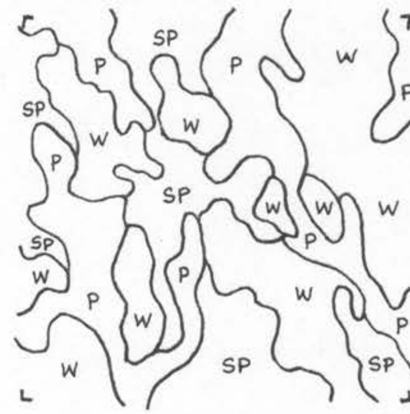


Color Infrared
with Stereoscope

Study site 1

SE¼, sec.32, T.98N., R.45W. Lyon county

Standard Soil
Survey Map



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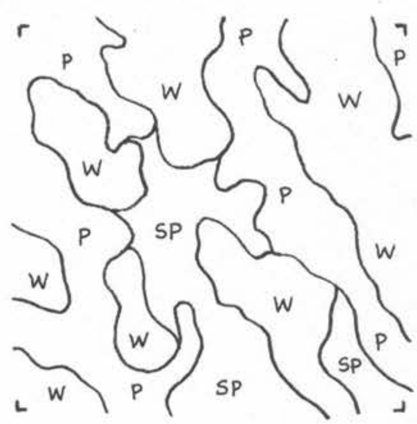
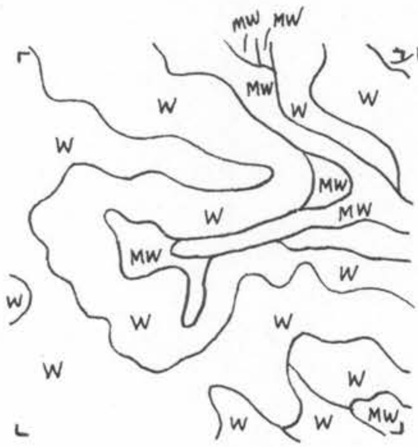


Color Infrared
with Stereoscope

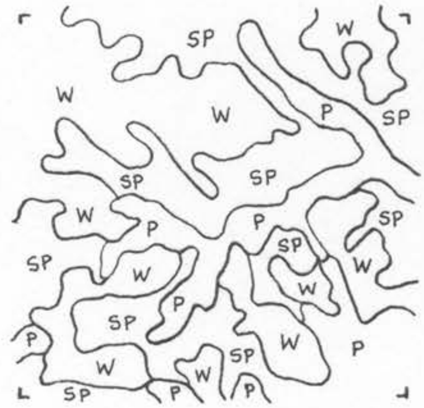
Study site 2

E½, SW¼, sec.33, T.98N., R.45W.
W½, SE¼, sec.32, T.98N., R.45W.

Lyon county



Standard Soil
Survey Map



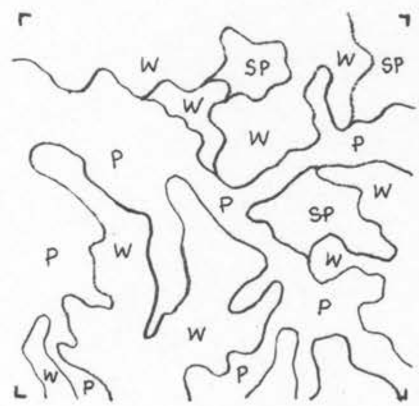
Color Infrared

Color Infrared
with Stereoscope

Study site 3

SE¼, sec.17, T.98N., R.45W. Lyon county

Standard Soil
Survey Map



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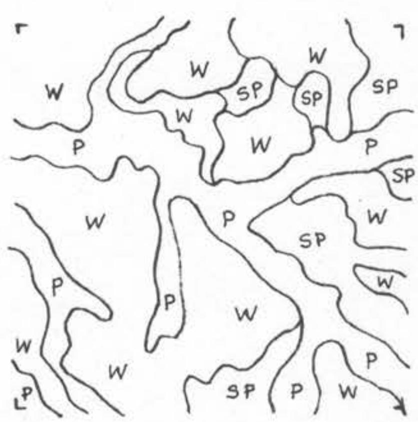


Color Infrared
with Stereoscope

Study site 4

NE¼, sec.8, T.98N, R.45W. Lyon county

APPENDIX B

Study Site Locations

on County Maps

GENERAL HIGHWAY AND TRANSPORTATION MAP

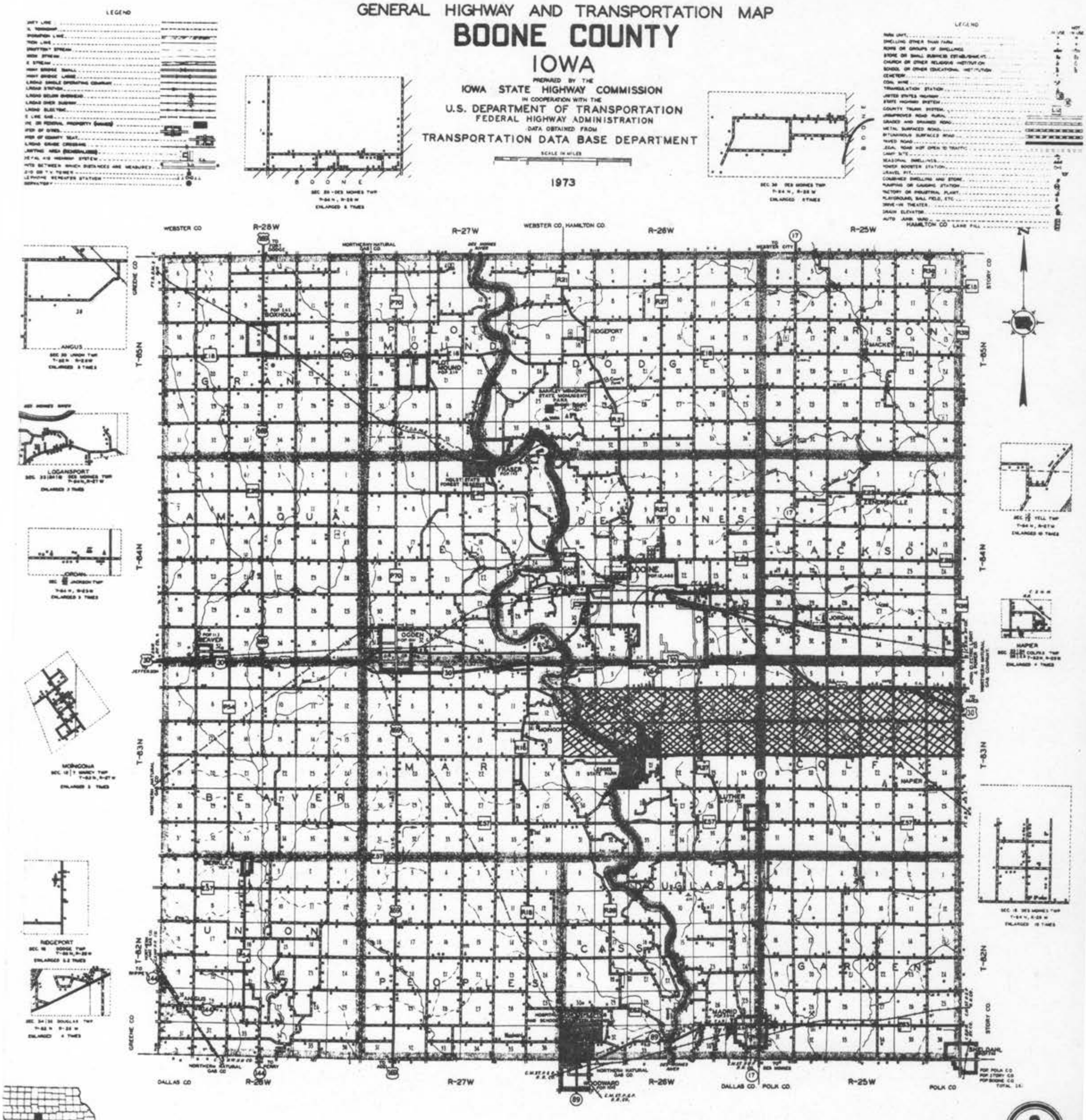
BOONE COUNTY

IOWA

PREPARED BY THE
IOWA STATE HIGHWAY COMMISSION
IN COOPERATION WITH THE
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
DATA OBTAINED FROM
TRANSPORTATION DATA BASE DEPARTMENT

SCALE IN MILES

1973



BOONE COUNTY

8

GENERAL HIGHWAY AND TRANSPORTATION MAP

BUCHANAN COUNTY

IOWA

PREPARED BY THE

IOWA STATE HIGHWAY COMMISSION

IN COOPERATION WITH THE

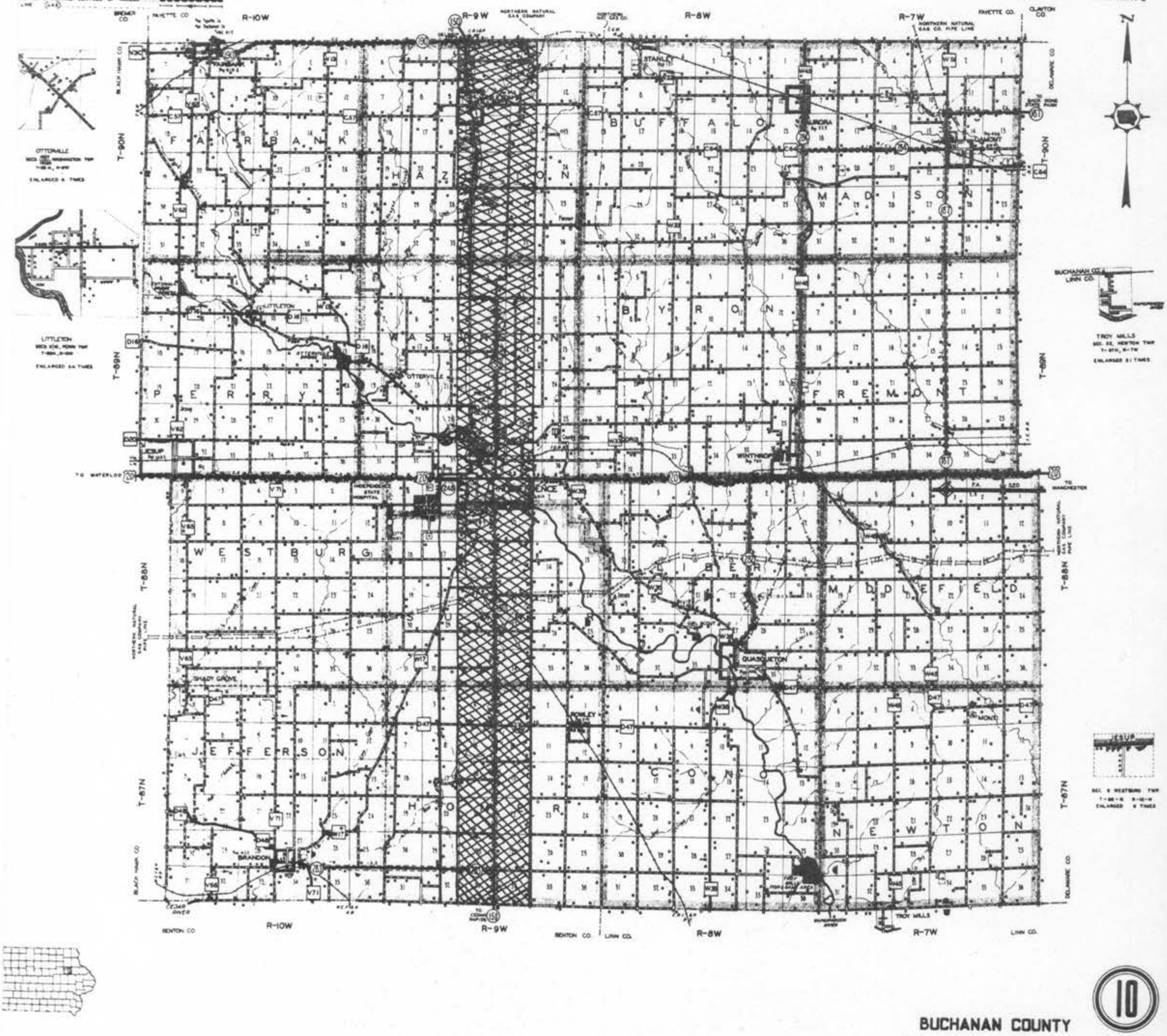
U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

DATA OBTAINED FROM

TRANSPORTATION DATA BASE DEPARTMENT

1973



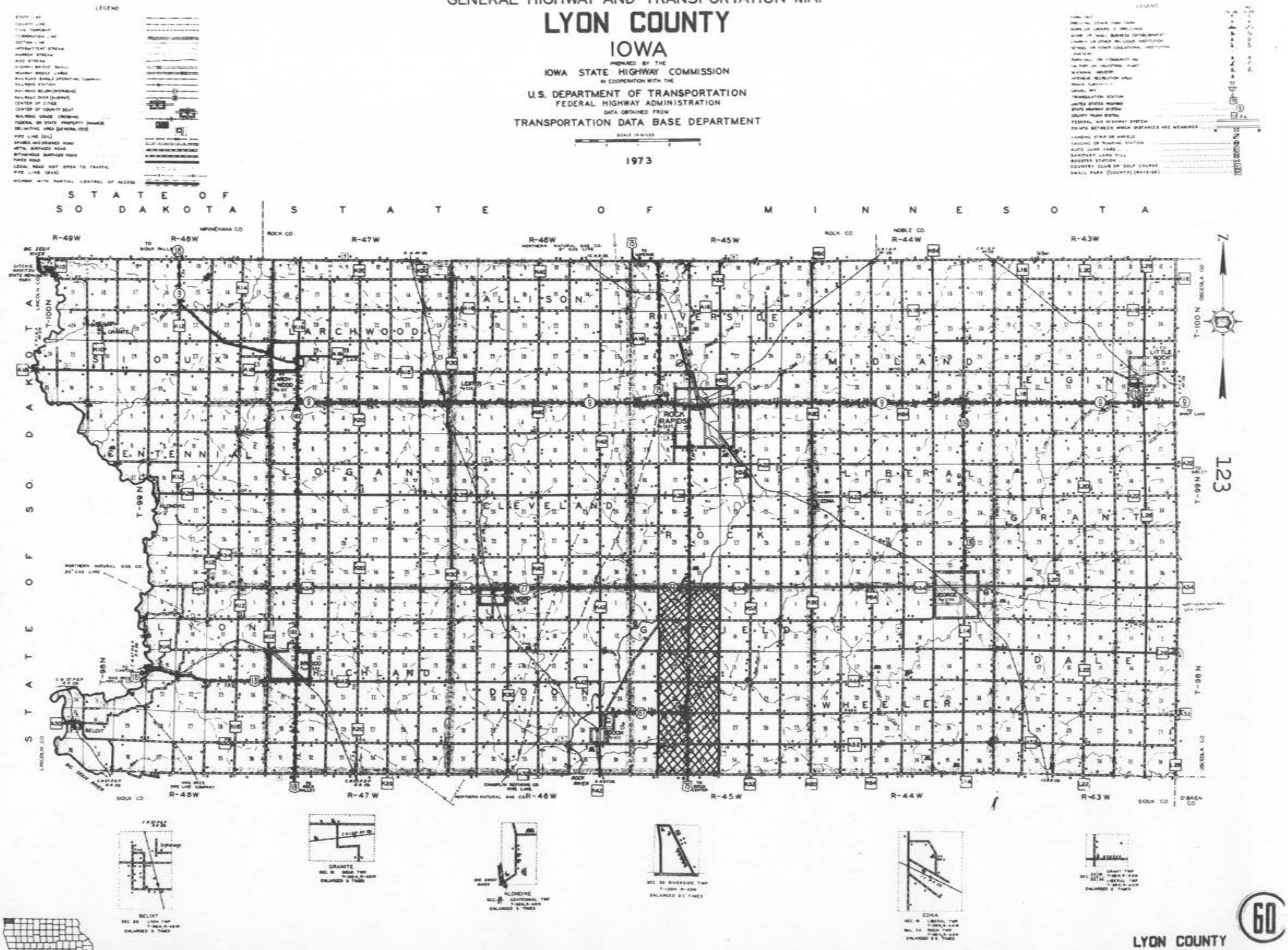
GENERAL HIGHWAY AND TRANSPORTATION MAP

LYON COUNTY

IOWA

PREPARED BY THE
IOWA STATE HIGHWAY COMMISSION
IN COOPERATION WITH THE
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
DATA OBTAINED FROM
TRANSPORTATION DATA BASE DEPARTMENT

1973



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